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CRANES; A STUDY OF TYPES AND DETAILS.

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[A paper read at the Cleveland Meeting of the American Society of Mechanical Engineers.]

In the study of any special class of machines, it is often conducive to a better understanding of the subject clearly to enumerate the several types or forms in which the machine is used, and also to consider each of its more important details separately, rather than in their combination with other elements of the mechanism. It is proposed in the following pages thus to treat the subject of cranes.

The only English text-books descriptive of cranes are Glynn's, which treats of English practice in crane building as it existed more than thirty years ago, and sundry catalogues published by English dealers in machinery as a means of advertising the products of the various builders of cranes for whom they act as selling agents. The practice represented in the former is now almost obsolete, by reason of the improvements which have been effected, and the latter consist of little but a series of pictures of various cranes, without descriptive text, and with no information as to the details of their construction.

The building of cranes has long been recognized in Europe as one of the most important subjects in the field of mechanical engineering, and cranes of many forms are there seen applied to an almost infinite

variety of uses. In America, on the contrary, cranes are but little used or appreciated, in comparison, at least, with the extent of their application in European countries. It is the purpose of this paper to present to American readers a brief classification and description of the most important types of cranes, and a similarly brief study of the more important elements entering into their construction, the object of the latter inquiry being to determine, if possible, the best forms of elements to be adopted.

With a better knowledge of crane construction will surely come a better appreciation of their economy and value as labor-saving machines. In hundreds of mills and workshops heavy material is now moved and handled by manual labor at an expense so much in excess of the cost of doing the same work far more rapidly and conveniently by cranes, that the saving effected by the latter would yield an annual profit of from twenty to fifty per cent. upon their first cost, while in many cases this outlay would be entirely repaid by the economy of one year's use.

CLASSIFICATION OF CRANES.

A *hoist* is a machine for raising and lowering weights. A *crane* is a hoist with the added capacity for moving the load in a lateral or horizontal direction.

All cranes, therefore, are provided with hoisting mechanism, and, in addition, must be capable of moving the load in one or more horizontal directions. This second function is effected in some types of cranes by simply pushing the load, in others by the operation of a distinct mechanism.

Cranes are most clearly classified by reference to their modes of transferring their loads horizontally; and, thus considered, are found to divide themselves into the following groups namely:

1. *Rotary.*—In which the load is revolved around a fixed centre, such as a mast or column.

2. *Rectilinear.*—In which the load is moved in straight lines in one or more directions.

Both types of cranes are subdivided into two general classes as to their movements, namely:

(*A.*) *Fixed.*—When their supporting members are fixed in some permanent location.

(*B.*) *Movable.*—When the crane as a whole can be moved about.

And into four other general classes as to their source of motive power, namely:

(*a.*) *Hand.*—When the motions, either vertical or horizontal, are effected by manual power.

(*b.*) *Power.*—When the motions are effected by power derived from line shafting driven by a stationary engine or other fixed motor.

(*c.*) *Steam.*—When the motive power is derived from a steam engine attached directly to the crane itself and moving with it.

(*d.*) *Hydraulic.*—When the motive power consists of hydraulic pressure obtained from a pump or accumulator, and carried to the crane by pipes.

A further distinction is covered by the term locomotive, which is applied to cranes (usually of the rotary type) which are capable of propelling themselves upon a roadway or track.

Rotary cranes comprise the following principal types:

1. *Swing Cranes.*—In which the central mast is pivoted to the floor and roof of the building, and the load is suspended from a block fixed at the outer end of an arm projecting horizontally from the mast, the only horizontal motion being one of rotation.

2. *Jib Cranes.*—In which the central mast is pivoted to the floor and roof of the building, and the load is suspended from a trolley traveling in and out upon an arm or jib projecting laterally from the mast.

3. *Column Cranes.*—Which consist of a jib crane constructed to revolve around or upon a fixed column forming the support of a building or floor.

4. *Pillar Cranes.*—In which the central column or pillar is entirely supported by a heavy foundation built at its base, and the load is suspended from a boom projecting from the pillar and revolving with it or around it.

5. *Derrick Cranes.*—Which consist of a jib crane for yard use, the upper end or pivot of the mast being held in position by guy-rods or stays, instead of by attachment to a roof or ceiling.

6. *Walking Cranes.*—Which consist of a pillar or jib crane mounted on wheels and arranged to travel by power or by hand upon one or more rails.

7. *Locomotive Cranes.*—Which consist of a pillar crane mounted on wheels, and provided with a steam engine and boiler, the power of

which is available for operating the crane and for propelling it upon its tracks.

Rectilinear Cranes comprise the following principal types:

1. *Bridge Cranes.*—In which a fixed bridge spans an opening, and the load is suspended from a truck or trolley capable of moving across the bridge.

2. *Tram Cranes.*—In which a truck or short bridge, from which the load is suspended, is arranged to travel longitudinally upon a pair of overhead rails, but is without capacity for transverse motion.

3. *Traveling Cranes.*—In which a rectangular space is provided with overhead tracks upon two opposite sides, and is spanned by a bridge arranged to travel longitudinally upon these tracks, the load being suspended from a truck or trolley capable of moving transversely across the bridge, so that the load may be moved to or from any point within the entire rectangle.

4. *Gantries.*—In which an overhead bridge is supported at each end by a frame or trestle extending downward and having wheels in its base to permit of travel upon two longitudinal tracks laid upon the ground so that the entire structure can move endwise upon the latter, and the road, which is suspended from a truck or trolley on the bridge, can be moved transversely across the bridge.

5. *Rotary Bridge Cranes.*—Which combine a rotary with a rectilinear movement and consist of a bridge having one end pivoted to a central pier or post, while the other or outer end travels on a circular overhead track or is supported by a gantry frame traveling upon a circular track upon the ground, the load being suspended from a truck or trolley traveling transversely across the bridge.

The above nomenclature will be adhered to in the following descriptions of crane construction.

HOISTING GEAR.

The most important factor in the economy and convenience of a crane is the mechanism by which the load is lifted and lowered, as it must necessarily come into action every time the crane is used.

In all applications of power, from whatever source derived, it must be remembered that the gearing of a machine can only modify the power applied in one or two ways, namely:

(1.) By reducing its velocity, and proportionally decreasing its force or "pull."

(2) By increasing the velocity, and proportionally decreasing the intensity of the power transmitted.

Under no circumstances, unless the motive force is increased, can power be gained except by a sacrifice of speed, or can speed be increased except by a sacrifice in power. If either or both must be increased without diminishing the other, it can only be accomplished by supplying more motive power.

The function of gearing, then, is to change the force or direction of the power applied. If it is well designed and constructed, this may be done with only a small loss from friction; while, if badly made, the gearing may absorb much power in wasteful friction of its moving parts.

In machinery for hoisting, the "purchase," or conversion of velocity into lifting power is usually effected partly by a multiplication of the ropes or chains of the tackle through which the load is suspended, and partly by gearing within the machine, which latter thus becomes an important feature in crane work. The gearing ordinarily used for this purpose consists either of spur-wheels and pinions, or of worm-wheels and worms, or both combined, and the smoothness and economy of power of the machine depend largely upon the manner in which the gearing is made.

A second feature of prime importance in the hoisting gear of a crane is the mode of sustaining the load, and guarding against its "running down" when the application of the motive power is discontinued. This has heretofore been accomplished, in machines having spur-gearing, by a ratchet-wheel, the pawl of which has to be entirely disengaged to permit lowering to occur, or by a brake which, when on, prevents all motion of the machine, and which requires to be held or thrown off both in hoisting and lowering. In machines having worm-gearing, the end is attained by a construction of their worm-wheels such that the friction between the worm and the wheel is sufficient to prevent the backward rotation of the worm under the pressure of the teeth of the worm-wheel caused by the load, the resistance thus generated sufficing to prevent the running down of the load.

The worm-wheel system is usually safe against accidents, but is not economical of power if the worm-gears are proportioned, as above explained, to hold the load suspended without running backward when the application of power ceases, as is usually the case. The spur-wheel system, on the other hand, is a constant and inevitable source of great

danger both to the load and to the operator. With the least carelessness in lowering, the load begins to descend with great velocity, and the mechanism is driven backward with corresponding speed and violence. If not checked, the load then practically falls as if unsupported. If too suddenly checked, violent strain is thrown upon the entire frame of the crane and on its gearing, which latter is thus liable to damage, and even to "stripping" or fracture, in which event the load falls. Where spur-geared cranes are operated by hand, this "running down" of the load involves a reversing or "flying back" of the cranks, which then frequently strike the men before they can escape beyond their reach. Accidents of this kind, resulting in injury to limbs, and even in loss of life, are constantly happening with common cranes, and are reported almost daily in the newspapers.

It is possible, however, so to proportion worm-gearing as to place it almost, if not wholly, upon a parity with spur-gearing in regard to economy of power transmitted, and by the use of cut worm-wheels driven by turned worms or pinions (the teeth of the wheel being formed by means of a chasing hob or cutter), so to construct worm-gearing that it becomes the best and most convenient form of gearing for use in crane mechanism. It is found that gearing thus made will not automatically support the load, and that the latter, if left suspended, will drive the worm-gearing backward; but in this case the descent of the load is quite slow, and no perceptible acceleration takes place, so that the worm-gears thus act as a governor to control the load. By the application of a small brake to the worm-shaft, this tendency is counteracted, and by connecting this brake with the levers which control the motions of the mechanism, the brake is easily made automatic, and thus securely holds the load whenever the crane mechanism is at rest.

In all cranes, except those of small size, provision should be made for one or more changes of speed in hoisting and lowering, so that the speed may be varied according to the load and the nature of the work to be done. Cranes operated by power *may* be so constructed that the maximum load can be lifted at the quickest speed; but they are usually so proportioned that this can be done only at a slow speed. By this plan, much economy of gearing, space, and cost is effected, and the practical efficiency of the crane for all ordinary uses is not impaired. The most perfect construction is one that permits a change of speeds

to be made whether the hoisting gear is in motion or at rest, and which sustains the load automatically while a change of speed is making.

The hoisting gear of a crane should therefore attain the following results:

(1.) Such changes in direction and velocity of the power applied as will give the desired motion to the load.

(2.) The accomplishment of this with a minimum loss of power through friction.

(3.) The safety both of the operator and the load under all conditions; to insure which, the load must be always self-sustained and incapable of "running down."

(4.) Capacity for changes of speed and for convenient transition from one of these to another at will, whether the gearing is in motion or at rest, and for the automatic support of the load during the act of changing speeds.

TRAVERSE GEAR.

In this, as in the hoisting gear, good design and construction are essential to economy of power, and frequently to safety against accidents.

In some types of rotary cranes, no traverse mechanism exists, except an arrangement of parts which provides for the rotation of the crane. In others, such as jib and derrick cranes, provision must also be made for moving the truck or trolley horizontally on the jib, and the same provision is required for moving the trolley of bridge and traveling cranes traversely on the bridge. In all such cases, a separate mechanism, distinct from the hoisting-gear, has heretofore been employed, and is still sometimes desirable or convenient. When employed, its parts should be as few and simple as possible, and it should be so far independent of the hoisting-gear as to permit either to be used at any time separately or conjointly. In power cranes provision should be made for accelerating the speed of the trolley travel whenever the nature of the work admits of it. The best possible result is attained when travel of the trolley is effected without varying the vertical position of the load, and without causing useless movement of the hoisting chain or rope over the sheaves through which it supports the load, which movement would involve much additional friction, and cause rapid wear of the chain or rope.

In traveling cranes, a point of great importance is the parallelism

of the bridge travel with the longitudinal tracks. Any defect here results in increased resistance to traction, and any considerable error might cause derailment. In traveling cranes, as heretofore built, the use of flanged wheels has been relied upon to prevent derailment, and the propulsion of the bridge has been effected by a transverse shaft extending the whole length of the bridge, and connected by gearing with the truck-wheels supporting each end of the bridge, so that, by revolving the shaft, the truck-wheels would be rotated, and the bridge be thereby propelled, provided the adhesion between the wheels and the rails was sufficient. In some instances, where the adhesion has not been sufficient to prevent slipping, a cast-iron rack has been laid adjacent to the longitudinal tracks, and extending their whole length, and pinions, gearing into this rack, attached to the axles of the truck-wheels, so that propulsion is effected independently of the adhesion of the truck-wheels to the track. If the load were always central on the bridge, and the motive power always applied to this shaft at the centre of its length, this plan would answer well, although it is somewhat clumsy; but in practice the load is constantly varying in position, and the motive power is applied at one end of the long transverse shaft, so that torsion of the shaft induces a considerable variation in the travel of the opposite ends of the bridge. This error is a constantly varying one, according to the portion of the load resting upon each truck, as determined by the position of the trolley, the load being never equally distributed between the two trucks, except when it is exactly in the centre. It follows, therefore, that this system of bridge travel, although operative, is radically defective, and that its use involves a constant loss of power by needless friction, and entails a proportionate amount of wear and tear of rails, wheels, and driving gear.

A better and more simple method of bridge propulsion has lately been introduced, by means of which the longitudinal motions of the bridge are effected by *pulling* each of its ends, simultaneously and at equal speed, in the desired direction. For this purpose, light wire cables are used, which, by a very simple and ingenious arrangement of guide-sheaves, are made to act as a "squaring device," to hold the bridge at all times perpendicular or square to the tracks upon which it travels. By this system, the friction of traction is reduced to a minimum, and the danger of derailment from unequal travel of the opposite ends of the bridge entirely obviated.

From the above facts, it becomes evident that a perfect system of

bridge propulsion must hold the bridge always absolutely square with its tracks, and must propel the opposite ends of the bridge in the same direction, at the same time and at the same speed, however unequally the load may be distributed. It is desirable also that, in large cranes at least, provision be made for starting the bridge slowly from a state of rest, and then increasing the speed, and also for varying the speed, while the bridge is in motion.

CHAINS VERSUS ROPES, AND CHAIN-WHEELS VERSUS DRUMS.

In almost every type of crane, the load is primarily carried upon a flexible cord of some kind. This usually consists of rope, either hemp or wire, or of chain. Each of these has distinctive merits and objections.

Ropes have the advantage of being formed of many parts or fibres, so that no splicing or welding is necessary in their manufacture; and they thus have an assured and practically uniform strength throughout their length.

Chains, on the contrary, consist of a series of independent links, each of which is formed from a straight bar, and welded, so that a single imperfect weld injures the whole, the strength of a chain being obviously limited by the strength of its weakest link. By care and good workmanship, however, this danger can be avoided, in which case the chains becomes as safe as the rope, and much more durable.

Where a rope is used, the hoisting-gear must necessarily include a drum or barrel, upon which the rope is wound up when hoisting takes place. Chains may also be thus wound up on a barrel, and this has heretofore been the common practice when chains have been employed in crane construction, and a prominent feature in cranes of large capacity has usually been a proportionately large "winding-barrel" to receive the chain. A chain, however, admits of another mode of construction, which consists in substituting for the wide barrel or drum a pocketed "chain-wheel," consisting of a narrow wheel or sheave, of a width only slightly greater than that of the chain, and having formed upon its periphery a series of indentations or "pockets," exactly corresponding in size and shape with the links of the chain, so that the chain and the pockets fit together accurately, and slipping of the chain upon the chain-wheel becomes impossible. It thus follows that rotation of the chain-wheel causes positive motion of the chain at a speed equal to the circumferential velocity of the wheel, in a manner precisely

similar to the motion of a rack driven by a pinion, or of one spur-wheel driven by another.

To be used in this way, it is necessary that the chain should have a constant and uniform "pitch," that is, that all the links should be exactly alike, so that the distance from link to link shall be always the same (just as in spur-gearing the spacing or pitch of the teeth must be uniform), and also that the pitch or spacing of the pockets of the chain-wheel corresponds accurately with the pitch of the chain. If this be done, and if the chain have a cross-section of such area that, when carrying the full load, it is not strained to its elastic limit, or to a degree which will cause any permanent elongation of its links, then a chain may be thus used, in engagement with a pocketed chain-wheel, as well and as safely as on a barrel. Indeed, a properly shaped wheel of this kind is much easier on the chain than a winding-barrel or drum, for the reason that the latter has a cylindrical surface, while the bearing face of the former is not cylindrical but polygonal, the bed or bottom of each pocket being tangential to the radius at its centre, and so presenting a flat surface for the parallel sides of each alternate link to bear upon. When the chain is wrapped upon a cylindrical barrel, on the other hand, the straight sides of every alternate link, being tangential to the surface of the barrel, can each touch it at one point only, the link being unsupported throughout the rest of its length, and the tendency of the strain induced by the load is to bend each of these links to the contour of the barrel. This effect may be easily seen in any chain which has been wrapped, under severe strain, upon a cylindrical barrel, unless the diameter of the barrel be very large. The spiral grooving of a barrel does not remedy this fault, although it affords a much better bearing for the chain than a plain cylinder; which latter is only permissible for small chains and light loads.

For heavy cranes, hemp ropes are rarely used, owing to the size and multiplicity of parts required, and to their rapid wear. They are also inadmissible where liable to be exposed to much heat, as, for instance, in a foundry. Wire ropes are more available, and are often employed; but these also wear rapidly, unless the sheaves and barrels around which they pass are of large diameter, while this requirement, if met, reduces the effective height of hoists and necessitates more parts or gearing to obtain the necessary purchase, and augments the bulkiness of the machine. Either material involves resort to a large winding-barrel or drum.

The usual and best device for large cranes is a well-made chain, and this, when used with pocketed chain-wheels and sheaves, gives the best and most satisfactory results, and leaves nothing to be desired. The adoption of this plan dispenses with winding-barrels, preserves the shape, and therefore the durability, of the links of the chain, and in every way simplifies and compacts the mechanism.

The relative merits of the several systems may now be summed up as follows:

(1.) *As to the Sustaining Cord.*

Hemp Ropes.—Admissible only for small cranes not in frequent use and not exposed to the weather or to heat.

Wire Ropes.—Available under any ordinary conditions, but involving a winding-barrel of large diameter and large sheaves; not economical of space.

Chains.—Possessing, if well made, all advantages and the greatest durability; *common chain*, requiring a winding-drum, but permitting it and the sheaves to be of smaller diameter than with wire rope; *pitch chain*, dispensing with a drum and admitting of the use of a narrow chain-wheel.

(2.) *As to the Winding Device for Hauling In and Paying Out the Rope or Chain.*

Winding-Drums or Barrels.—These must have a diameter and length such as will enable them to receive the whole length of rope or chain to be hauled in by winding it upon their surface in one coil, without overlapping. In large cranes, the load is usually carried upon four, six, or even eight parts of rope or chain, so that the length to be wound up amounts to four, six, or eight times the effective hoist, and the dimensions of the barrel thus become very large. Moreover, this barrel must either be caused to travel longitudinally on its shaft, so that the rope or chain as it leads off shall be always in the centre of the crane and hoisting mechanism (which method of construction involves serious complication and greatly widens the space occupied by the gearing), or the rope or chain, as it uncoils, be permitted to vary in position from one end to the other of the barrel, in which case it is nearly always out of centre, thus inducing objectionable lateral strains and causing greater friction and wear.

Chain-Wheels, with Pockets.—These require a width only slightly greater than a single part of the chain, and a diameter merely sufficient

to give the proper engagement with it, so that both dimensions become much smaller than in a winding-barrel, and the total space occupied is but a small fraction of that required for the latter device. The *chain-wheel* is fixed in direct line with the chain, and all lateral strains are avoided, while the flat bearings afforded for the chain by the pockets preserve the shape of the links and protect them from bending strains. The slack chain, after passing over the wheel, falls into a proper receptacle below.

From this analysis of the facts is deducted the proposition that chains, if well made, constitute the best form of flexible cord for sustaining the load in a crane, and that a well-constructed *chain-wheel* (as contra-distinguished from a winding barrel) is the best form of device for hauling in and paying out the chain; and therefore, the best method of crane construction involves the use of these two elements.

A REMARKABLE ERROR IN THE COMMON THEORY OF THE TURBINE WATER WHEEL.

By J. P. Frizell.

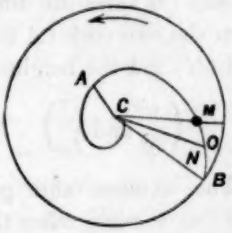
All writers who have attempted a theoretical discussion of the turbine water wheel, have agreed in representing the centrifugal force operating to increase or diminish the discharge of the wheel, by a certain head. The difference, namely, between the head due the rotatory velocity of the wheel at the point where the water enters the wheel, and the head due the rotatory velocity of the wheel at the point where the water leaves the wheel. Among those who have done so to my certain knowledge are Weisbach, Redtenbacher, Rankine, Morin, and Bresse.

To all these philosophers the very careful and complete experiments of Mr. Francis on turbine wheels have been accessible for the last thirty years; giving them, had they so desired, abundant means of comparing their theories with facts. They appear to have ignored these experiments entirely, and to have contented themselves with exhibiting the results of mathematical reasoning. Even in the late valuable and carefully considered treatise of Weisbach, no attempt is made to reconcile his conclusions with the results of these experiments or to explain the discrepancies that must have been known to exist.

To the engineer who attempts to compare theoretical results with those of experiment, nothing becomes apparent sooner than that the above-mentioned principle wholly fails to represent the action of centrifugal force. Mr. Francis, in his "Hydraulic Experiments," expresses the opinion that centrifugal force plays a less important part in the turbine wheel than is assigned to it by mathematicians, though he does not attempt any inquiry into the foundation of the formula by which that force is represented; being probably, like many others, content to regard it as one of those scientific truths which are only true on paper but not true in practice; as a principle which water ought, in deference to eminent authority, to observe, but which its habitual wilfulness and perversity lead it to disregard.

It is always worth while when we meet with a principle, so called, which does not represent facts, to inquire carefully whether it be well founded in theory.

The principle in question is demonstrated by Weisbach in "Mechanics of Engineering, etc." Coxe's translation, p. 610, and more concisely in the introduction to his later work "Hydraulics and Hydraulic Motors," by Prof. DuBois. I reproduce the latter, though both are essentially the same, and this may be regarded as a type of the methods by which the principle is supposed to be demonstrated.



"If the path $C\,A\,B$, in which a body moves, is not at rest, but turning about an axis C, it imparts to the body a centrifugal force P, by reason of which the body either performs work or work is performed upon it, according as it departs from or approaches the axis of rotation C. Let M be the mass of the body, ω the constant angular velocity with which the path turns about C, and let r denote the variable distance $C\,M$ of the body which is moving in the path $C\,A\,B$. We have the centrifugal force of the body (Art. 13) $P = \omega^2\,M\,r$, and for the work done by this force while the body describes an element

$M\,O$ of its path, and hence, while the radius $C\,M = r$ is increased by an amount $N\,O = d\,r$,

$$d\,W = \omega^2\,M\,r\,d\,r.$$

Hence for the whole work

$$W = \frac{\omega^2\,M\,r^2}{2}.$$

Now the velocity of rotation at the distance r is $v = w\,r$, and therefore

$$W = \frac{M\,v^2}{2} = \frac{v^2}{2g}\,G.$$

When we substitute instead of the mass M, the weight $G = M\,g$.

If the body begins its motion, not at C, but at any other point, A, at a distance r_1 from C, where the velocity of rotation is $v_1 = \omega\,r_1$, we have for the work done, while passing from A to M,

$$W = \tfrac{1}{2}\omega^2\,M\,r^2 - \tfrac{1}{2}\omega^2\,M\,r_1^2 = \tfrac{1}{2}\omega^2\,M\,(r^2 - r_1^2) = \tfrac{1}{2}M\,(v^2 - v_1^2)$$
$$= \frac{(v^2 - v_1^2)}{2g}\,G.$$

If, then, a body moves in a rigid path or groove which revolves about a fixed axis, the vis viva of the body is increased or diminished by the product of the mass (M) and the difference of the squares of the velocities (v^2 and v_1^2) at the two ends (A and M) of the path, or by the product of the weight (G) and the heights

$$\left(\frac{v^2}{2g} \text{ and } \frac{v_1^2}{2g}\right)$$

due to these velocities. The increase takes place when the motion is from within outward, and the decrease when the motion is from without inward."

Now who can fail to perceive that this demonstration is entirely erroneous, assuming as it does that ω represents the angular velocity of the body M. In other words, that this body has the same angular velocity as the revolving disc. The body M has a motion along the path $C\,A\,B$ independent of its rotatory motion imparted by the disc. This movement is partly angular and partly radial. The angular element of this motion must be added to or subtracted from the angular motion of the disc to find the true angular velocity of the body M on which the centrifugal force depends. This would lead to a very com-

plicated expression for the centrifugal force, involving the equation of the path in which the body moves.

The above expressions would be true if the body M had merely a radial movement on the revolving disc, but are entirely erroneous as soon as an angular element is added to that movement. How entirely a formula deduced from such assumptions must fail to represent the action of centrifugal force in a turbine wheel will appear from this consideration. All the above-mentioned writers prescribe as a condition of efficiency that the water at its exit from the wheel should have the same velocity as the latter, in the opposite direction. In other words, that the angular velocity of the water at that point must be null, while a moment's reflection will show that their formula for the centrifugal force can only be true upon the assumption that the water has, here as well as elsewhere, the full angular velocity of the wheel.

I append the following example of the application of this formula. In Mr. Francis's experiments of 1851 upon a Fourneyron Turbine, he measured the discharge and useful effect at all velocities, from the condition in which the wheel was held fast by the brake, to that in which it ran entirely free. In the table "Hyd. Exp.," p. 33, the discharges are all reduced to a uniform fall of 13 feet. It by no means follows, however, that the variations in the discharge, under these circumstances, are wholly due to changes in the centrifugal force.

As the velocity increases from zero, there is a progressive change in the resultant direction of the water entering the wheel, and it comes more and more into coincidence with the direction in which the water leaves the guides. There is a progressively diminishing loss of head due to abrupt change of direction. Presumably, these two directions coincide, and the loss of head ceases, at the velocity corresponding to the maximum efficiency of the wheel. Between these two limits of velocity, therefore, viz., O, and the velocity of maximum efficiency, we should expect the discharge to increase faster than is called for by the formula for centrifugal force. The results of experiments show nothing of this kind.

From the point of maximum efficiency to the point where the wheel runs free, there is an increasing deviation between the direction in which the water enters the wheel and that in which it leaves the guides, and consequently, an increasing loss of head. Between these latter limits, therefore, we might expect the increase of discharge to be less than that called for by the formula for centrifugal force. Between

the limits *O* and wheel running free, we might expect these two causes of discrepancy to neutralize each other, and the formula for centrifugal force to represent the total increase of discharge between these limits better than between any other limits.

The velocity of the wheel, running free, was expt. 23. Internal circumference 37·766 feet per sec.

$$\text{Ext. circum. } 37{\cdot}766 \times \frac{8{\cdot}292}{6{\cdot}75} = 46{\cdot}393 \text{ ft. per sec.}$$

The difference between the heights due these velocities is

$$\frac{\overline{46{\cdot}393}^2 - \overline{37{\cdot}766}^2}{2g} = 11{\cdot}288.$$

The discharge of the wheel, standing still, under a head of 13 feet was (Exp. 43) 136·725 cubic feet per sec. According to the theorem under consideration, the centrifugal force should have the same effect in increasing the discharge as an addition of 11·288 feet to the head. The discharge, therefore, should be

$$136{\cdot}725 \sqrt{\frac{24{\cdot}288}{13}} = 186{\cdot}88 \text{ cubic feet per sec.}$$

The actual discharge in Expt. 23 was 165·37 cubic feet per sec.

Induced Currents in Reciprocal Movements.—In an article published by du Moncel, on Dec. 16, 1882, upon the effects produced in the Griscom motor, he showed that when one of the poles of a permanent magnet is moved before a straight electro-magnet there are three successive induced currents: 1. The one resulting from the approach of the magnet, which is inverse and momentary. 2. Another, which is manifested during the whole passage of the magnet before the magnetic nucleus, and which is indirect. 3. A third, resulting from the removal of the magnet, which is momentary and which, although in the same direction as the first, corresponds to a direct current, because the inductive current is then exerted on an opposite extremity of the magnetic nucleus. Of these three currents only one has the same energy at the different points of the magnetic path. It is the one which corresponds to the passage of the magnet from one end to the other of the nucleus, and it belongs to the category of currents which du Moncel has called currents of polar interversions, and which he is now investigating.—*La Lum. Elec.*, Jan. 27, 1883. C.

BÉTON IN COMBINATION WITH IRON AS A BUILDING MATERIAL.

By W. E. WARD, Port Chester, N. Y.

[A paper read at the Cleveland meeting of the American Society of Mechanical Engineers.]

If society is indebted to the restless spirit of progress for most of its modern comforts and conveniences, it certainly is not yet a debtor for any methods which successfully guarantee immunity against calamities from fire. While other departments of industry have received the benefits of improvement, the continuous and persistent use of combustible material for exposed portions of buildings has limited the intrinsic elements of the art of building construction, and confined improvements only to matters of design.

Incombustible materials are easily obtained, and much better adapted to the purpose for every apparent reason. Doubtless the question of increased cost, both in money and in time required for more thorough construction, may be in a measure responsible for the tardiness in adopting safer methods, and, in addition to greater expenditure, there may have been a want of confidence in the fire-proof methods which have been offered to the public for adoption. The importance of this question induced the writer, in 1871 and 1872, to make some experiments in a new and special direction, for the purpose of ascertaining whether a practically fire-proof building could be designed and constructed, at a comparatively moderate cost.

The incident which led the writer to the invention of iron with béton occurred in England in 1867, when his attention was called to the difficulties of some laborers on a quay, trying to remove cement from their tools. The adhesion of the cement to the iron was so firm that the cleavage generally appeared in the cement rather than between the cement and the iron.

The line of experiments which followed were confined exclusively to working up the reciprocal value of béton, in combination with iron, in the construction of beams which were designed for supporting floors and roofs made of the same material. In this particular, the facts were conclusively developed beyond question, that the utility of both iron and béton could be greatly increased for building purposes, through

a properly-adjusted combination of their special physical qualities, and very much greater efficiency be reached through their combination than could possibly be realized by the exclusive use of either material, separately, in the same or in equal quantity.

Experience had long ago proved, that, uprotected iron, associated with combustible materials, is altogether unreliable for building purposes when exposed to a severe fire test; but it has been demonstrated that, if iron is well protected by a heavy clothing of béton, its integrity can be safely depended upon under almost any emergency.

When all doubts were removed concerning the reliability of the several combinations of materials required in the construction, a building, embracing the following radical, new features, was erected, for dwelling purposes, near Port Chester, N. Y. Not only the external and internal walls, cornices and towers of the building were constructed of béton, but all of the beams, floors, and roofs were exclusively made of béton, re-inforced with light iron beams and rods.

Furthermore, all the closets, stairs, balconies, and porticos, with their supporting columns, were moulded from the same material. The only wood in the whole structure being window-sashes and doors, with their frames, mop-boards, and the stair rails; thus excluding everything of a combustible nature from the main construction.

Béton can be used in any form of construction, and is able to serve the requirements of any architectural or decorative effects. All the exterior portions of this house, which are more or less ornamental in their functions, were made of béton in place during the progress of the work. In the interior of the house, the cornices, stiles, and panels of the ceilings are formed of béton, and covered with the hard finish usual in such work. There appears to be no limit to the reproduction in béton of any form used in stone masonry or in stucco. The proportions of material composing the béton for the work varied in strength to meet the requirements of the different parts of the structure: the heavy walls needing the least proportion of cement, while the beams, floors, and roofs required a much larger proportion. Only the best quality of Portland cement, clean beach sand, and crushed blue-stone were used in combination with iron for constructing the building.

The proportions of cement used for the heavy wall work were one part of cement to four parts of sand and fine gravel, thoroughly mixed

dry, and dampened with only sufficient water to give it the consistency of well-tempered moulding sand.

A finely crushed and screened, hard, blue lime-stone was found to be better adapted for use in combination with the béton than a coarse sized stone filling, because small sized stones pack closer than large ones, thereby realizing a proportional saving in cement. The tests made to ascertain the comparative transverse strength of different compositions proved that the bond was stronger in béton made with small stone. In breaking test sections made of béton in the form of bricks, the fracture of those filled with small stone was almost invariably across the stone lying in the line of fracture, while the fracture of the test bricks made with a filling of stone three or four times larger, showed a frequent tearing away from the bond between the béton and the larger stone filling, the composition of the béton being the same in both cases.

The proportions of cement and coarse beach sand and gravel, used in re-inforcing iron beams for floors and roof supports, were one part of cement to two parts of sand and gravel. The size of the iron beam, selected for an experimental test, was a four-inch I beam of lightest pattern, twelve feet long, weighing thirty pounds to the yard, and its safety load was limited to eleven hundred and fifty pounds. A plank mould was made the length of the iron beam, twelve inches deep by five inches wide, in the bottom of which a layer of béton was first moderately tamped down to an inch in thickness; then the iron beam was laid on the course at equal distances from each side of the mould, and settled down on the surface of the course of béton to a good bearing. This brought the top surface of the beam seven inches below the top of the mould. The work of filling and tamping the courses was then continued until the mould was filled.

The reason for placing the iron beam so near the bottom of the mould, was to utilize its tensile quality for resisting the strain below the neutral axis when this composite beam was exposed to heavy loads, while the béton above this line was relied on for resisting compression from load strain. The béton became thoroughly hardened in about thirty days, when the following tests of transverse strength were made. It was placed upon suitable supports, with a bearing of three inches at each end. A lever was adjusted so as to bring the testing load on a knife-edge bearing at the centre of the beam. Weight was then applied to the long end of the lever, until the stress on the centre of the

beam reached nine thousand five hundred pounds. Under this load there was a deflection at the centre of the beam of seven-sixteenths of an inch, but not a sign of rupture appeared at any point.

The load was then removed, and the beam returned to the original line it occupied before the test, showing that the combination possesses the essential quality of elasticity in addition to the enormous increase of capacity to resist strain over that which was possible for either material to sustain if used separately, and in the same quantity.

It is suggested that for future construction that an inverted ⊥ beam would furnish a more preferable distribution of iron in the composite beams than the I beams which were used.

The result of this experiment demonstrated the reliability of the composite beam of iron and béton, and showed that the adhesion of the cement to the iron could be relied on under heavy strains; and warranted the adoption of béton reinforced with small rods for the floors and roofs.

The beams for supporting the floors throughout the house were placed at such convenient distances apart as to insure perfect safety to the floors, and, at the same time, affording ample opportunities for producing the best effects in deep, paneled ceilings.

The beams were all moulded in position, where they belonged, both for the floors and roofs, and after the same method that the experimental beam was made. The iron beams varied in width and weight per yard in accordance with their length and the prospective load; the largest being nineteen feet long by seven inches wide. When the combination beams were completed and ready for the floors and roofs, heavy planks were firmly placed in position and securely supported between the beams; the upper surface of these plank foundations being adjusted on a level with the top surface of the moulded beams. These planks served as the bottom of the floor moulds, and after the béton comprising the floor was hardened, they were removed.

Channel ways had been moulded in the walls, on a line with the top of the beams, for the purpose of supporting the outer edges of the floors.

Before the floors and roofs were laid, care was taken to cover all the supporting surfaces with paper, to prevent the adhesion of floor and roof sections to their supports. This precaution was necessary, to

permit the movement of the floors and roofs that would unavoidably take place under varying temperatures and loads.

A part of the experimental system contemplated an attempt to warm the house by passing currents of heated air between the floors and ceilings, and up through flues, made in close proximity to each other, for that purpose, in the interior walls of the building, and it was necessary to core out a liberal area of lateral openings through the upper portion of the beams, in order to permit a free circulation of heated air. The ceilings rested upon flanges projecting from the lower portion of the beams.

Instead of using sand and gravel, or both, in combination with cement, for floor and roof construction, the preliminary experiments that proved the superior value of broken blue stone for massive work, led to the adoption of washed, fine screenings from the same material for the floors and roofs, because its greater angularity than gravel insured a stronger bond in the work than could be realized by using sand and gravel.

The proportions of materials used for this purpose were: one part of Portland cement to two parts of the fine stone screenings. The preparations being completed for laying down the floors, a thin course of the béton was first put on, and evenly tamped down, to about an inch in thickness, over the whole space intended to be covered. Then rods of iron, five-sixteenths of an inch in diameter, were placed both longitudinally and laterally, at a uniform distance of eight inches apart, over the whole surface. Then, on this, a final layer of two inches in thickness was carefully tamped down. In about eight hours the béton was hardened sufficiently to allow the application of the top surface, which was floated down with a half-inch coat of cement and fine beach sand mortar, made of equal parts of each. This completed the final finish, and made the whole thickness of the work three and a half inches. It will be observed that for the same reason as in beam construction, and, as before explained, the iron rods for reinforcing were placed near the bottom of the work, so as to resist the tensional stresses due to the load, while that due to compression in the upper portion would be sustained by the béton alone. In this manner, and by this process, over thirteen thousand square feet of flooring and roofing were constructed to fill the requirements of the building.

The only test of any consequence upon the combined strength of the

floors and beams together was made on a section of the widest floor in the house, where the beams are eighteen feet span and six feet between centres. Casks of plaster were placed upon the floor over the beam, forming a triangular load of thirty tons, which was sustained without any injury to the floor, or measurable permanent deflection. The dimensions of the beam that sustained this load were seven by sixteen inches, and eighteen feet span, reinforced in its lower portion with a seven-inch I beam, weighing fifty-five pounds to the yard.

This test indicates that, in addition to its admitted fire-resisting qualities, the reinforced system of construction challenges comparison with other methods of building in matters of strength and of cost, whether for buildings requiring long or short floor spans.

Experimental tests were made with several partition walls, to ascertain how thin it would be advisable to construct them for light walls where the load was small. The result of the experiments showed that the resistance of partitions eight feet in height, made of béton two and a half inches thick, and reinforced with one-quarter inch iron rods, was equal to brick walls eight feet high, and eight inches in thickness.

It is the opinion of the writer that for the great majority of houses required for dwelling purposes, a system of thin reinforced double walls, with a space of from six to ten inches between them, and reinforced cross connections every two or three feet apart, to unite the outer and inner walls firmly together, could be built up to thirty or forty feet in height, at a cost not exceeding that of first-class brick work.

Besides an equal economy in the construction, such double walls would be an incomparably better defense against stormy weather than the best quality of brick work, because the absorptive capacity of béton is so much less than that of brick.

Thus, all things considered, the thin double-wall system commends itself as containing the main, desirable qualities, essential to the outer and inner wall construction of dwelling houses, embracing, as it would, a sure protection against both fire and dampness, and the means for thorough ventilation. Besides the special fitness of the reinforcing system for floors, roofs, beams, and thin walls, it is an interesting question whether the same system may not be also applicable, and advantageously extended to a more general use in many engineering

requirements; especially in situations where immense weights must be sustained, and where iron construction alone is difficult of application, notably in such an important work as the Hudson River Tunnel, where its tubular form is constructed with an outer cylindrical shell of flue iron, and lined inside with heavy brick mason work: much of this tunnel rests upon a treacherous bed of silt, and might be made absolutely safe from a rupture caused by settlement, induced by vibrations resulting from railroad traffic in addition to its own weight, by adding to a thin brick lining a strong béton about sixteen or eighteen inches thick, and work in it three or four courses of iron bars, of suitable size, laid longitudinally and in sufficient quantity to bear any amount of strain that settlement or any other cause might bring upon it. Rings of flat bar iron, interspersed in the béton lining, a few feet apart, would further add to its security.

Although the writer has no personal knowledge of the methods which are to be used in filling the interior of the Statue of Liberty, to be erected on Bedloe's Island, New York Harbor, he is of the opinion that a filling of béton, reinforced with iron, furnishes the best method of increasing the stability of that colossal statue.

The reinforced béton system has also been employed with admirable results in heavy foundations for stationary engines. The writer, three years ago, mounted a two-hundred-and-fifty-horse-power, tandem, compound engine, of very heavy pattern, on a reinforced béton bed, twenty-three feet long, five feet wide, and seven feet deep. It is apparently as firm and hard as a single mass of granite of those dimensions. The outboard bearing of the main shaft is also mounted on a single block of the same kind of construction. The cost of these foundations was less than the estimate made for the same in first-class brick or stone mason work.

It has also been used for lining a reservoir of 96,000 gallons capacity, which was blasted into a ledge.

Another great advantage realized in reinforcing béton with iron, is that the iron overcomes its tendency to check in hardening, within useful limits, however large the surface may be if the distribution of the iron through the work is made with ordinary good judgment. This is demonstrated in the instance of entire freedom from shrinkage checks in the single section of béton flooring laid in the drawing-room of the house under consideration. Its dimensions are eighteen by thirty-six feet, three and a half inches thick, and there is no trace of a

check throughout its whole extent. After a period of eight years since it was laid down, and six years of that time it has been, during winters, more or less subjected to unequal strains from expansion and contraction, caused by its exposure to unequal temperatures, while employed as a transmitting medium of heat for warming the room. The method of heating the house is as follows:

In the centre of the cellar is a heating chamber, measuring eleven by sixteen feet, and eight feet in height. Within this chamber is placed an ordinary cast-iron heater, of a capacity for burning about three hundred and fifty pounds of coal per day. Openings were made, about twelve inches apart, all around the top of the surrounding walls of the chamber, leading outwardly to the spaces between the first floors and the cellar ceilings, and also up through the flues within the interior walls which communicate with the spaces between the second-story floors and ceilings beneath them. Vertical iron pipes, of suitable size are located so as to connect the open spaces between the cellar ceilings and first floor, with a large, closed trunk or passage-way, which extends nearly all around the inside of the main wall foundation, under the cellar floor, and finally terminates in a large flue, which leads directly under and into the heating-chamber.

This comprises about the whole system of arrangements in the construction for warming the house with heat radiated from the floors and interior walls.

Its mode of operation simply consists in the body of warmed air passing from the heating-chamber upward, through the walls and under the floors, and in its passage giving up its surplus heat to the surfaces of these flues. As the air becomes reduced in temperature, it naturally descends back through the pipe and trunk passage-ways, provided for its return to the heating-chamber, where it is again recharged with heat. It will readily be seen, that, by this method, a continuous circulation will be maintained with the same quantity of air; and furthermore, that the velocity of the current will vary with the difference of temperature of the air when leaving the heating-chamber and when re-entering the heating-chamber.

By this system, there are about fifty-five thousand cubic feet of the interior of the house heated by radiation, through about thirty-five hundred square feet of floor and wall surfaces, and the capacity of the heating-chamber is fourteen hundred cubic feet, so there is one cubic foot of heated air to forty cubic feet in the house.

The temperature of the air in the heating-chamber averages, in very cold weather, one hundred and seventy degrees, and after delivering its surplus heat to the floors and interior walls, its temperature registers fifty-eight degrees in the flue where it re-inters the heating-chamber for reheating; showing that one hundred and twelve degrees of heat had been given up and utilized for warming purposes. With ordinary care in managing the furnace, a temperature of sixty-eight degrees can be uniformly maintained on the first floor, and from sixty to sixty-two degrees on the second floor, with a consumption of about three hnndred and twenty-five pounds of anthracite coal per day in the furnace.

The temperature, produced by this system of heating, is free from the objectionable extreme variations so common with other modes of heating. The walls and floor form such large heating surfaces that the temperature is uniform in all portions of the rooms, while the air is not vitiated by escaping gases or heated dust, as is universally the case where furnaces or steam pipes are used for heating.

It is not claimed that its economic results per pound of coal are greater than that which is claimed for the steam or hot water systems, but if the latter were required to make as liberal a provision for the renewal of fresh air in the interest of an equally good ventilation, the percentage of useful results per pound of coal from steam or hot water would average no higher than the former.

The rain-water falling upon the roof passes through two six-inch iron pipes which are set in the wall, extend across the cellar, and reach into a béton tank in the rear tower, and holding 5,000 gallons, whose water level is thirty inches below the level of the roof. This inverted siphon also forms a distributing system to the various points of consumption in the house, through short branch pipes connected to these mains.

There are also two other tanks made of béton, and holding 3,000 gallons, situated under the main tank; one of these sustains a head of over twenty feet of water, and has never given any indications of leakage.

In regard to the important factor of cost involved in this system of béton construction, its average for beams, floors and roofs, including the supporting platforms for laying them down was a fraction over sixty cents per square foot. This cost also includes the reinforcing iron beams and rods. The cost of the heavy wall work, not including cornices, was about twenty-four cents per cubic foot which includes

the cost of plank moulds, required for building up the walls. The advantages that most favored these economical results were cheap material and cheap labor.

The bulk of the material required for the work abounds in inexhaustible quantities, and is always maintainable at moderate cost. The essential skill required, consists in a simple knowledge of the right proportions of material, and of its proper manipulation, both of which can be acquired in a half-day's practice. The most inexperienced laborers can do all the work of the most elaborate béton construction, excepting only the surface finishing, and this, with all the other work can be superintended by one competent, experienced builder.

Along with the foregoing data, it may be well to include an interesting feature of some experiments that were made to test the heat-enduring qualities of béton. A number of large test bricks were made of the same proportion of materials that were used in the construction of the walls, and in subjecting them to different intensities of heat to see how much they could withstand before breaking up; there was no perceptible difference observed in the tendency to fracture whether the bricks were exposed to a gradual or rapid heating. Not one of them broke when subjected to a white heat. Several were heated to a bright red heat, and then plunged into a bath of cold water. They withstood this test without showing a decidedly damaging fracture, and one of the bricks was exposed to an alternate heating and cooling, three times before breaking up.

These results were a surprise, and they suggested the advantage of such a material for the walls of buildings, as a sure defence against uncontrollable conflagrations. The facts that appear to be established by this line of experiments are:

First.—That a system of iron beams reinforced with béton can be made to sustain weights many times greater than the iron beams alone can withstand without reinforcing.

Second.—That floors and roofs can be economically made of béton reinforced with iron rods, capable of sustaining heavier loads, with a less number of supporting beams, than any other system of flooring and roofing now in use, *at equal cost.*

Third.—That the system of reinforced beams and floors affords advantages for a more perfect system of heating buildings uniformly than by the steam or hot water systems.

Fourth.—That the sanitary requirements of complete ventilation are plainly within the reach of this system of construction.

Fifth, and finally.—That it affords a perfect defense against the interior destruction of buildings by fire.

The intrinsic worth of béton construction appears most valuable in furnishing the elements of fireproof construction; and thus inaugurating a reformation in the prevailing system of building based on the principle that safety from loss by fire can be more economically realized through reformation than by exclusive dependence on insurance to indemnify for losses by fire. The amount of capital destroyed by such losses appears almost fabulous, and has been estimated by insurance authorities to be over one hundred million dollars annually in this country. This enormous amount takes no cognizance of the losses due to the disturbance of business relations, and to labor by such enforced interruptions of industry, but the sum of the losses accounted for seems to be enough to awaken an interest in the discovery of some effective remedy for reducing their magnitude.

Yet, if the remedy is only to be found in building more thoroughly, its adoption may remain doubtful so long as the hazardous way of building, and the rates for insuring hazardous property occupy their present relations to each other. Such radical departures from conservative ideas of building as are herein described must necessarily find a slow recognition, and reach public favor like any other innovation—through small and gradual beginnings—and wait until their their merits grow to be regarded as a public necessity.

But, however destructive to the material wealth of the country may be the vast losses of property by fire, they sink completely out of view when compared with the terrible sacrifices of human life that are constantly resulting from unsafe building construction.

Against this fearful consequence of it, humanity can reasonably protest, and claim, for the sake of human welfare, that such structures as hotels, theatres, public schools, and all other places of public resort shall be made invulnerable to the assaults and horrors of fire catastrophies.

In conclusion, it is to be hoped that these experiments may shed enough additional light on the fireproof building question to make the way easy for reducing reinforced béton construction to a system, that will deserve public confidence, and ultimately lead to its common adoption.

THE GRINDSTONE.

By J. E. MITCHELL.

[Abstract of remarks made at the stated meeting of the Franklin Institute, June 20, 1883.]

I have nothing new to say about the grindstone; it is the same homely article it was over three hundred years ago, but the application of it has been greatly improved and its uses largely increased, and it now plays a most important part in our machine shops and manufactories, as without its use it would be almost impossible to carry on these works. The Baldwin Locomotive Works consider them of sufficient importance to keep seven Newcastle grindstones, of two tons weight each, constantly at work for grinding off the rough iron work of locomotives preparatory to painting or polishing, and for this purpose they could scarcely be dispensed with, besides running a considerable number of smaller stones for sharpening the various tools for turning and cutting metals.

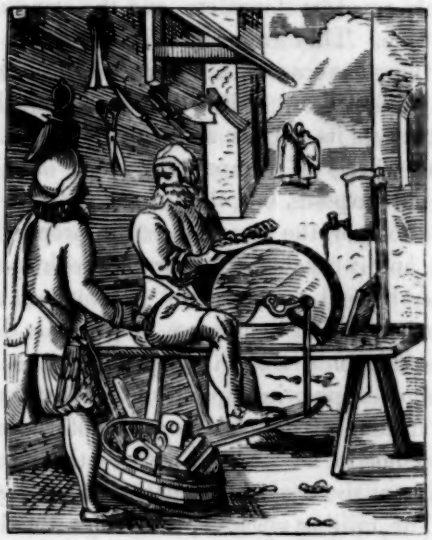
Grindstones are also used for grinding off the faces of cast-iron pullies, by running the pulley rapidly in one direction and bringing the face of it in contact with a grindstone (kept well supplied with water) running in an opposite direction. This renders the pullies perfectly true, and does the work more rapidly than turning them off in a lathe. A very hard, sharp grit Newcastle stone is found to be best adapted to resist the necessary pressure.

A column was thrown on the screen representing thirteen specimens of the principal American and foreign grindstones, the thickness of the grindstone when in actual use being represented in the column. This has been prepared as one of a series of similar columns intended to represent all the grindstones known both here and in the Old World. They are being prepared by the speaker under the direction of Professor Baird, Secretary of the Smithsonian Institution, and are to be placed in the National Museum in Washington. They will be arranged as a colonnade or court, within which will be placed glass cases containing all the known forms of sharpening stones.

Fragments of every specimen represented will be mounted on glass slides, and ground thin enough to represent the shape, etc., of the particles when placed in a microscope. This will enable the operator to form a correct idea of the cutting properties of the various forms of

sandstones which are used as grindstones. Over twenty-five hundred of such specimens of the various sorts of building stones have been prepared, which are now on exhibition in the National Museum, a few of which, through the kindness of Professor Baird, I am enabled to throw upon the screen to-night. These have been prepared by Mr. Merrill, of the Museum, who deserves great credit for the patient skill displayed in their preparation.

The following historical facts relating to this ancient mechanical implement, compiled from Lewis's pamphlet, may be of interest, viz.:



A GRINDSTONE OF THE SIXTEENTH CENTURY.

In the whole range of mechanics, with all modern developments and enlarged capabilities, there has been applied no mechanism nor process yet able to supersede the grindstone in its peculiar office. It is the one thing in mechanic arts that improvement has not added to, or invention displaced; while the pruning hook and plough are of equal antiquity, the spirit of improvement has touched both but left the grindstone unchanged. Its utility in the early ages was great, and science has not lessened its value any by its perfection of other means for like results. It has been found in use among uncivilized people, and yet has its place with nations most advanced. Writers of fiction

knew it would not conflict with the appearance of truth to ascribe it a place among barbarians. It is among the few implements of handicraft mentioned in scripture, though there only named for milling purposes; it is the same in form and in universal use—a round revolving stone. In a scriptural research for the articles of handicraft mentioned then, we can look through the "eye of a needle" and find the grindstone beyond, its origin lost in the darkness of antiquity. It is not meant to confound the millstone of antiquity with the grindstone of to-day, which the encyclopædia mentions as "a flattish circular stone of various diameters, employed in the cutting and sharpening of edged tools, precious stones, etc., and the grinding of steel, glass, pottery and the like. They are made of sandstone, or sandstone grit." The grindstone now has scarcely a wider capability or greater usefulness than when we first heard of it. Although limited as its qualifications may be, it serves its purpose as nothing else can. Improvement has furnished us wheels of composition which only to some extent serve some of its purposes, but the grindstone still remains unsupplanted. It is a tool of the utmost nicety in proper hands and properly understood, and is capable of performing with speed and precision its limited agency beyond the powers of any modern tool. It is perhaps found best handled in its purpose of grinding dies for cut nails, where its proper use constitutes an occupation not to be attained very perfectly by a short apprenticeship with it. That known as "beadstone," used by makers of cut nails, is a tool of the utmost perfection of workmanship, not to be meddled with by the inexperienced, however lightly, without the result being noticed by the eye of the experienced nailer. The milling machine, the planer, the file, the lathe and emery wheel, do much of the work of the grindstone, but it still performs to perfection its needful though limited purposes. The importance and nicety of it, as a means to a purpose, is only known by those who know how to prepare and keep it in order.

Its utility or importance could not be guessed at, were one to look at a crooked and badly kept grindstone; but in the hands of those who know its merit, with its even surface running as true as any turned wheel, it will perform work with a rapidity and precision attainable by no other means. In the hands of those who are learned in its use and keeping, it is capable of adaptation to intricate and fine work, but with those who do not understand it, it is rude, and the very opposite

of what the educated craftsman would select for any purpose of fine employment.

An heirloom of antiquity, but used among us as we received it, and without any attachment or improvement; capable of its complete functions only when well kept and well applied, and this is only found with those whose craft-education is solely to handle it. It alone can cut and shape expeditiously that which is prepared to cut and shape all other hard materials—cast-steel hardened. It is still employed to give the finest edge, the most even surface, the brightest polish, and is the quickest to accomplish it. The emery wheel does but a few of its purposes, and nothing that we have could supply its place. The file has its own peculiar uses, but in contact with the grindstone, its thousand small cutting edges would be reduced to polished plainness. It is found a necessary implement on the farm, and is still required where the finest of instruments are made, or the hardest of metals are worked. It has come to us as we have it, and in all likelihood will pass on down to other ages the same—a simple circular stone, swiftly revolving on an axle.

It accompanies those who "go down to the sea in great ships," and moves along the frontier with the advance of civilization. All nations use it, and it is perhaps, with all, the one piece of mechanism that bears the same form, and is the same in principle. More or less directly it takes part in the greatest modern material enterprises; it has, no doubt, assisted to fashion the implements of many of the lost arts, and is still needed in many of the requirements of arts of the present day.

As ages revolve and invention gives to the world new devices, may it be found more the agent in forming the ploughshare and pruning hook than in sharpening the sword.

Twinkling of Stars during Auroras.—Montigny finds that the scintillation of the stars increases during auroras, the increase being more strongly marked in winter. The difference is most noticeable in the northern stars. When a magnetic disturbance is shown at the Brussels Observatory, at the same moment with the observation of scintillation, the intensity often increases. He proposes to make the phenomenon the subject of a special investigation, in order to discover the cause of the remarkable coincidence.—*Bull. de l'Acad. de Belge*, iv, 303. C.

THE GLOVER TOWER AND THE WORKING OF SULPHURIC ACID CHAMBERS.

By Moses A. Walsh.

[Read before the Chemical Section of the Franklin Institute, June 5, 1883.]

It may be conceded that systematic observation, with proper qualification of observers and sufficient means, is a never-failing source of improvement.

In the mechanical and chemical arts this continues to be true where development is well advanced no less than during the early stages of development.

The construction of tower which I submit to the notice of the Section admits of the widest application in the chemical arts, but for the present I speak of it only as applied to the Glover and Gay-Lussac towers in the working of sulphuric acid chambers.

Last year, Mr. Henry Bower, the president of the Chemical Section, went to inspect some improvements I had made in the construction of towers and sulphur burners. In a conversation I had with him at the time, he remarked that there was a lack of mathematical precision in the action of all towers in use. A tower might work well or it might not work well. There were no means known by which it could be definitely determined beforehand that a tower would work in a precise manner after it was constructed; and when once constructed there was no directional control over its working. I showed him what I had done in the way of constructing towers designed, at least, to work with exactness.

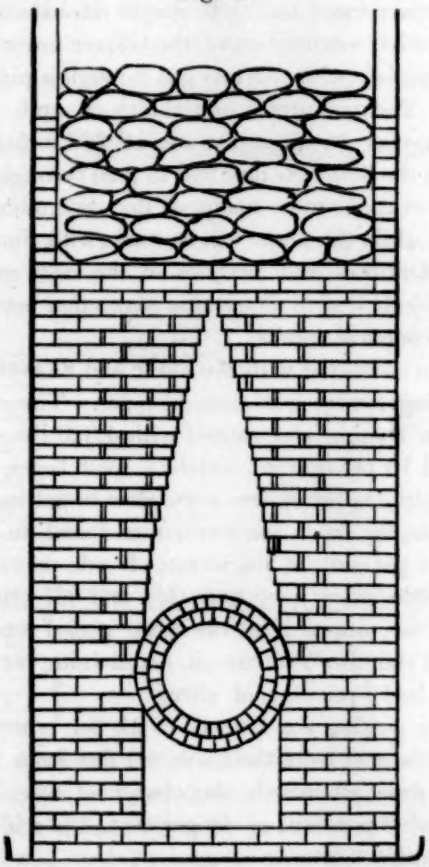
I also pointed out a line of experiment by means of which, if not exactness, at least great improvement would result. I invoked Mr. Bower to use his influence with the Manufacturing Chemists' Association to induce it to undertake the burden of conducting the experiments. I have not since heard from him.

It is a fact that many Glover towers, especially, do not act in the smooth, efficient way of denitrating nitrous vitriol mentioned by Lunge. Where the acid from the Glover tower is used in the manufacture of alkali, the occasional presence of a small quantity of N_2O_3 is not observable, and even in larger amounts not prejudicial; but where the acid is used in other branches of manufacture, as is exclusively the case in America, such as the manufacture of alum, chlor-

hydric acid, etc., the presence of a small amount of nitrous acid becomes seriously manifest, as more than one manufacturer has found.

It was just such manufactures as these, where even traces of nitrous acid were prejudicial, that led me to seek a method by which certainty of denitration in the Glover tower could be insured.

Fig. 1.



that under the best circumstances 2½ per cent. to 3½ per cent. of nitrate of soda were required to maintain the waste of nitre going on in the chamber process. Little or no nitrous acid would be found in the acid from the tower, while the amount of nitrate potted was small, below 3 per cent.; but when the percentage was increased from any

The incentive to seek in this direction was increased by the fact

cause, such as starting up after stoppage, the acid from the tower would contain very sensible quantities of nitrous acid, and the chamber process would be robbed of "nitre" by so much as went to injure the manufacture in which the acid was used. Loss of "nitre" elsewhere in the process could be accounted for and controlled. In each case brought under observation, the re-absorption of nitrous acid at the bottom of the tower was found to be due to mechanical causes originating in the defective construction of the Glover tower. One of these towers was supplied with burner gas through a pipe of 900 inches sectional area. The gas entered underneath an arch perforated with sixteen holes having an aggregate area of 260 inches, and the whole of the gas from the 900-inch pipe had to pass through these holes.

Interior observations were made of the descending acid and the ascending gases while the tower was at work, with simultaneous observations in the chambers and analyses of the acid coming from the tower. The object was to determine connection between mechanical conditions and chemical results.

The chambers connected with the tower had 88,000 cubic feet capacity, not counting towers nor draught pipes. The chambers having been stopped for repairs, were started with 4,320 lbs. seconds sulphur in 24 hours and 10 per cent. of nitrate. Acid began to form at once in the tower, but the chambers were slow in getting into condition, and the acid running from the tower was found to contain nitrous acid equal to 4 per cent. of the nitrate of soda potted. An assay of this acid was made every hour, and this and all other observations recorded. At the proper time the nitre potted was decreased, and Gay-Lussac and chamber acid run on, maintaining between the two as nearly as could be 10 per cent. of nitre.

The charge by potting was reduced to $2\frac{1}{2}$ per cent., and it was not until then that the acid from the tower ran free from nitrogen oxides, and if at any time afterwards the charge of nitre by potting was increased beyond 3 per cent. or $3\frac{1}{2}$ per cent., the acid from the tower was found to contain "nitre."

The acid in the tower was observed to descend in large drops and broken streams. These results were arrived at:

1. The acid distributed in the upper portions of the tower was collected into streamlets in the lower portion.

2. The acid in drops and streamlets, and in proportion to the volume of the drops and streamlets, is in a condition more favorable for the

absorption of nitrous acid than it is for denitration by sulphurous acid.

For comparison afterwards I state results of working these chambers for one whole year.

Chamber space per lb. sulphur, 20·37.

Nitrate of soda potted, 2·8 per cent.

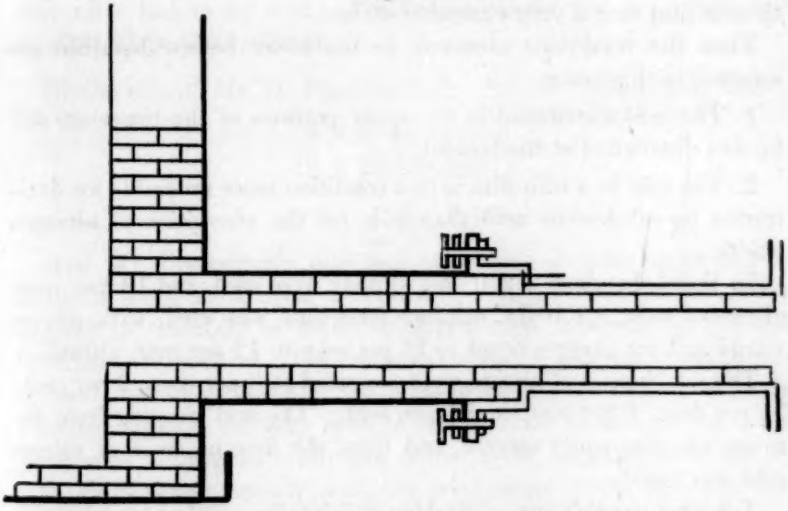
By the rule in Mr. H. Pemberton, Jr.'s paper, the case stands thus:

$$10 \times 20{\cdot}37 = 203{\cdot}7$$

instead of 280 to 300. The yield of H_2SO_4 was 288 per 100 sulphur consumed.

Mr. Pemberton, Jr., omitted to state this last result in the enforcement of his rule.

Fig. 2.



Being called upon to design and construct a Glover tower for another set of chambers, of 148,000 cubic feet capacity, I determined to avoid most of the defects observed in towers previously constructed. With this object, I had recourse to a device which I had designed some years before. This was to dispense with the arch entirely, with its disadvantages of contracted apertures and heavy side thrust, and also to avoid the use of lead covered bearings. This latter plan is quite inadmissible in the construction of the Glover tower, although I have heard of Glover towers being so constructed, with what result I never heard; but to run such a tower dry, even for never so short a

time, must result in disaster. Lead covered iron bars are bad, as I have seen, because the acid trickling over the lead wears grooves in it and eventually exposes the iron to destruction.

It will be seen from the accompanying sketches that my device is something in the form of a Gothic arch, forming a large chamber at the bottom of the tower, and so constructed that the whole weight of the contents of the tower rests upon the bottom. It will be seen from Fig. 2 that the bond of the tower, with the pipe, effectually protects the lead from the action of the hot burner gas, if at any time the tower has to be run dry. If one stands inside the chamber. Fig. 1, he can see that some hundreds of apertures are provided for the ascending gases, and that the descending acid can nowhere form a drop or a streamlet. It must of necessity form an extremely thin and continuous film over a very extensive surface.

Thus the conditions observed in the tower before described are reversed in this tower.

1. The acid distributed in the upper portions of the tower are still further distributed at the bottom.

2. The acid in a thin film is in a condition more favorable for denitration by sulphurous acid than it is for the absorption of nitrogen oxides.

In these chambers 7,250 lbs. sulphur were used, and 10 per cent. nitrate of soda, 8,400 lbs. sulphur for a time was used, with nitrous vitriol and pot charges equal to 11 per cent. to 12 per cent. nitrate.

The pot charges of nitrate were decreased to 3 per cent., 2 per cent., $1\frac{1}{2}$ per cent., 1 per cent., and $\frac{3}{4}$ per cent. The acid running from the tower was frequently assayed, and from the first no trace of nitrous acid was found.

Taking a month's run of 30 days, 217,500 lbs. sulphur were burned, and 2,466 lbs. nitrate of soda potted. This gives a chamber space of 20·4 cubic feet per lb. sulphur burned, and 1·13 per cent. nitrate of soda potted.

The daily test of nitrous vitriol for the month showed that the average supply to the chambers from potting and nitrous vitriol combined was equal to 10·11 per cent. nitrate of soda.

$$10{\cdot}11 \times 20{\cdot}4 = 206{\cdot}24.$$

The yield of H_2SO_4 for a whole year was 300·48 from 100 sulphur. But the average consumption of nitre for the year was 1·48 per cent.

This result was traceable to three causes:

1. Perfect absorption in the Gay-Lussac tower.

2. Perfect denitration in the Glover tower.

3. Practically eliminating the influence of some of the most serious causes of disturbance in the chamber process, viz., high and variable winds, gusts of wind and the states of the atmosphere indicated by the barometer.

In another set of chambers of 98,692 cubic feet capacity, working without Glover or Gay-Lussac towers, 4,320 lbs. sulphur were used in 24 hours with a consumption of 8 per cent. nitre. This gives a chamber space of 22·8 cubic feet per lb. sulphur. Where 4,800 lbs. sulphur were used, giving a chamber space of 20·5 cubic feet, 10 per cent. nitre had to be used. The yield of H_2SO_4 for one whole year was 294·24 per 100 sulphur.

By the rule of Mr. H. Pemberton, Jr., the case would stand thus:

$$8 \times 22{\cdot}8 = 182{\cdot}4$$
$$10 \times 20{\cdot}5 = 205{\cdot}$$

Mean, 192·7

And Mr. Pemberton's rule that percentage of nitre multiplied by chamber space shall equal 280 to 300, giving a mean of 290, when applied to chambers in which sulphur is used, is wrong by just this difference of one-third. The rule applies, and is followed when pyrites is used instead of sulphur, for making sulphuric acid, as then the chamber space is virtually reduced one third on account of the introduction of atmospheric nitrogen through the combustion of the Fe into $Fe S_2$ simultaneously with the combustion of the S_2. The rule when applied to the use of sulphur, is a very safe one to follow, as respects yields, as it should give the best results even where skill is not the best, but where the best return for outlay of capital upon sulphuric acid chambers is sought, that is dollars and cents, the chambers will have to be worked by another rule, viz., the product of the percentage of nitre by the number of cubic feet of chamber space per lb. sulphur burnt in 24 hours shall equal 200.

I hope, with Mr. Pemberton, that others will give the result of observation and experience in this matter.

ON RADIANT MATTER SPECTROSCOPY: A NEW METHOD OF SPECTRUM ANALYSIS.*

By William Crookes, F.R.S.

For several years I have been examining the phenomena presented by various substances when struck by the molecular discharge from the negative pole in a highly exhausted tube. I have ventured to call this discharge "radiant matter," and under its influence a large number of substances emit phosphorescent light, some faintly and others with great intensity. On examining the emitted light in the spectroscope most bodies give a faint continuous spectrum, with a more or less decided concentration in one part of the spectrum, the superficial color of the phosphorescing substance being governed by this preponderating emission in one or other part of the spectrum. Sometimes, but more rarely, the spectrum of the phosphorescent light is discontinuous, and it is to bodies manifesting this phenomena that my attention has been specially directed.

For a long time past I have been haunted by a bright citron-colored band or line appearing in these phosphorescent spectra, sometimes as a sharp line, at others as a broader nebulous band, but having always a characteristic appearance and occuring uniformly in the same spot. The best way to bring out the band is to treat the substance under examination with strong sulphuric acid, drive off excess of acid by heat, and finally to raise the temperature to redness. The anhydrous sulphate thus left frequently shows the citron band in the radiant matter tube, when before this treatment the original substance shows nothing. I soon came to the conclusion that the substance I was in search of was an earth, but on attempting to determine its chemical properties I was baffled.

Much chemical evidence tended to support the view that the band might be due to a compound of lime. By neglecting the portion showing least citron band, and separating all the elements present which gave little or none, I could generally concentrate the citron band into a solution which—according to our present knowledge of analytical chemistry—should contain little else than the earths, alkaline earths, and

* Abstract of the Bakerian Lecture delivered before the Royal Society, May 31, 1883.

alkalies. Ammonia added to this solution would precipitate an earth, and in the filtrate oxalic acid would precipitate an insoluble oxalate, showing the citron band strongly. This was found on analysis to consist of strontic and calcic oxalates. The strontia being separated, the remaining lime formed an oxalate which gave the citron band.

So far all the chemical evidence went to show that the band-forming substance was calcium, and further tests tried with the purified oxalate confirmed this inference. Every analytical test to which it was subjected showed lime, and nothing but lime; all the salts which were prepared from it resembled those of lime, both physically and chemically; the flame spectrum gave the calcium lines with extraordinary purity and brilliancy; and, finally, the atomic weight taken with great care, came out almost the same as that for calcium, 39·9 as against Ca 40.

On further examination it was found that most native compounds of lime gave the citron band. It was found in clear and colorless Iceland spar, native calcic phosphate, a crystal of arragonite, a stalactite of calcic carbonate from Gibraltar, cinnamon stone (lime alumina garnet), iron slag from a blast-furnace, pink coral, commercial plaster of Paris, and most specimens of ordinary burnt lime.

Evidence stronger than this in favor of the view that the citron band was an inherent characteristic of calcium could scarcely be; but, on the other hand, there was evidence equally conclusive that the band was not essential to calcium.

Starting with a lime compound which showed the citron band, I could always obtain a calcic oxalate which gave the band stronger than the original substance; but if I started with a lime compound which originally gave no citron band, I could never by any means, chemical or physical, constrain the lime or the earthy precipitate to yield a citron band.

The only explanation that I could see for this anomaly was that the elusive citron band was caused by some element precipitated with the calcic oxalate, but present in a quantity too small to be detected by ordinary chemical means. The calcic oxalate was ignited and dissolved in hydrochloric acid, and fractionally precipitated in three portions with ammonic oxalate, the first and third portions being comparatively small. They were then tested in the radiant matter tube. All three portions showed the citron band, but the portion which came down

first gave the band decidedly the strongest, and the third portion precipitated showed it weakest.

It having been found that the substance giving the citron band formed a sulphate more soluble in water than calcic sulphate, four pounds weight of commercial plaster of Paris, which showed very faint traces of the citron band, were mixed with water and poured on a large filter. A few ounces of water were poured on, and after passing through, poured back, and the exhaustion repeated several times. The aqueous extract was then evaporated to dryness, ignited with sulphuric acid, ground in a mortar with small successive quantities of water, and precipitated with ammonic oxalate. The precipitate, ignited with sulphuric acid, showed the citron band very fairly, far more intensely than it was seen in the original calcic sulphate.

These experiments are conclusive in proving that the citron band is not due to calcium, but to some other element, probably one of the earthy metals, occurring in very minute quantities but widely distributed along with calcium, and I at once commenced experiments to find a more abundant supply of the body sought for. Amongst other substances tested I may note the following as giving a more or less decided citron band in the spectrum when treated with sulphuric acid in the manner indicated above: Crystallized barytic chlorate, heavy spar, common lime-stone, strontic nitrate, native strontic carbonate, crystallized uranic nitrate, commercial magnesic sulphate, commercial potassic sulphate, tobacco ash, Wagnerite (magnesic phosphate and fluoride), zircon, cerite, and commercial ceric oxalate.

Some specimens of zircon appeared sufficiently rich to make it probable that here might be found an available source of the citron-band yielding body. I found it in crystals from Green River, North Carolina, from Ceylon, from Expailly, from Miask (Oural), and from Brevig, and having a good supply of North Carolina zircons, these were worked up by a process given in detail in the paper.

I may condense a year's work on zircon,—over ten pounds weight of crystals from North Carolina having been worked up—by stating that the result was comprised in about 300 grains of an earthy residue, and about two ounces of oxalate, chiefly calcic; the former gave the citron band very well.

The zirconia prepared from these zircons, when tested, sometimes showed the citron band, and at other times none. A zirconia rich in citron band, fractionally precipitated by ammonia, yielded precipitates

of increasing richness, the last fraction showing the citron band strongly.

The calcic oxalate obtained from zircon gave unsatisfactory results, so attention was directed to the earthy residue. This was found to be of highly complex character, containing thoria, ceria, lanthana, didymia, yttria, and probably some of the newly-discovered rarer earths.

The position of the citron band in the spectrum falls exactly on the strongest absorption band of didymium, so that a piece of didymium glass or cell of solution of the nitrate entirely obliterates the citron band. This naturally suggested that the band was due to didymium.

Cerite was accordingly the next mineral experimented on. The powdered mineral tested in the tube in the original way gives a good citron band. The mixed earths after extraction were converted into sulphates, dissolved in water, and the cerium metals precipitated by long digestion with excess of potassic sulphate.

The precipitated double sulphates were converted into oxalates, and after ignition and treatment with sulphuric acid, the mixed ceria, lanthana, and didymia were tested in the radiant matter tube, but the merest trace only of citron band was visible.

This experiment proved the inadequacy of the didymium explanation, and further tests showed that not only could I get no citron band in pure didymium compounds, but the spectrum entirely failed to detect didymium in many solutions of the earth which gave the citron band brilliantly.

Attention was now turned to the solution filtered from the insoluble double sulphates. Potash was added, and the precipitate filtered off, and tested in a radiant matter tube. The spectrum, of extraordinary brilliancy, was far brighter than any I had hitherto obtained. Unfortunately, however, the quantity was too small to be subjected to very accurate chemical analysis.

Search was now made amongst other minerals rich in the rarer earths. Thorite was finely powdered, treated with sulphuric acid, and tested in the radiant matter tube. It gave the citron spectrum most brilliantly—equal in fact to the mixture of earths obtained from zircons at so great an expenditure of time and trouble. Orangite treated in the same manner gave almost as good a spectrum. Pure thorinic sulphate prepared by myself was found not to give the citron band, but three specimens prepared and given to me by friends all gave it, so it was not unlikely that in thorite and orangite might at last be found a good source of the long-sought element—that in fact the body I was

hunting for, if not thorina, might possibly be Bahr's hypothetical Wasium. Two pounds of orangite and thorite were extracted with hydrochloric acid. The solution was precipitated with potassic sulphate, taking the usual precautions to secure complete precipitation. A bulky precipitate ensued, which containad the thorina and cerium earths. These were separated and tested, and found to give only a faint citron band.

The solution of earthy sulphates soluble in potassic sulphate was precipitated with ammonic oxalate. The precipitate ignited with sulphuric acid, and tested in a radiant matter tube, gave the citron spectrum with great brilliancy.

Certain chemical facts concerning the behavior of the sought-for element which came out during the course of the tentative trials described in the paper considerably narrowed the list amongst which it might probably be found. All the evidence tends to show that it belongs to the group of earthy metals, consisting of aluminium, beryllium, thorium, zirconium, cerium, lanthanum, didymium, and the yttrium family, together with titanium, tantalum, and niobium. The sought-for earth is insoluble in excess of potash; this excludes aluminium and beryllium. It is not precipitated by continued boiling with sodic thiosulphate; this excludes aluminium, thorium, and zirconium. Fused with acid potassic sulphate, the resulting compound is readily soluble in cold water; this excludes tantalum and niobium. Evaporating to dryness with hydrochloric acid and heating for some time does not render the mass insoluble in water; this excludes titanium and silicium. It is easily soluble in an excess of a saturated solution of potassic sulphate; this excludes thorium, the cerium group, some of the numerous members of the yttrium group, and zirconium. The only remaining elements among which this elusive body would probably be found are those members of the yttrium family which are not precipitated by potassic sulphate.

The yttria earths form a somewhat numerous family. Fortunately for chemists, a mineral rich in yttria earths—samarskite—has been found lately in large quantity in Mitchell County, North Carolina, and to this mineral I accordingly now directed my attention.

The following list of elements of the yttrium and its allied families said to occur in samarskite and similar minerals may be considered complete to the present time.

Name.	Absorption Spectrum.	Hydrogen equivalent of Metal.* (Type of Oxide M_2O.)
Cerium	No	47·1
Decipium	Yes	57·0
Didymium	Yes	48·5
Didymium β	Yes	47·0
Erbium	Yes	55·3
Holmium	Yes	54·0
Lanthanum	No	46·0
Mosandrum	No	51·2
Samarium	Yes	50·0
Scandium	No	14·7
Terbium	No	49·5
Thulium	Yes	56·5
Ytterbium	No	57·9
Yttrium	No	29·7
Yttrium α	No	52·2
Yttrium β	Yes	49·7

Some of these claimants it is certain will not stand the test of further scrutiny. Thus samarium and yttrium β are in all probability identical; and I have not included philippium, as Roscoe has conclusively proved that this is a mixture of terbium and yttrium, and my own results confirm those of Roscoe. Moreover, some of these so-called elements will probably turn out to be mixtures of other known elements. But in the confessedly very imperfect state of our knowledge of the chemistry of these metals it is not safe for me in this research to assume that any one of them will surely not survive. The complete list as it stands will, therefore, be taken to contain all hitherto claimed as new, although it is almost certain to include too many.

In the second column "Yes" or "No" indicates whether the solutions give an absorption spectrum when examined by transmitted light. After numerous experiments I satisfied myself that the metal giving the citron band spectrum was not one of those giving an absorption spectrum. The possible elements, therefore, became narrowed to the following list: Cerium, lanthanum, mosandrum, scandium, terbium, thorium, ytterbium, yttrium, yttrium α and zirconium.

Of these the potassic sulphate reaction excludes cerium, lanthanum,

* As it is at present doubtful whether the oxides of several of the metals in this table belong to the type M_2O, M_2O_3, or MO, I have, for the sake of uniformity, and simplicity in calculating the values from the composition of their salts, by which these metals are chiefly discriminated, taken the type of oxide to be M_2O.

scandium, thorium, yttrium *a*, and zirconium, so there are left only the following:

Mosandrum,	Terbium,
Ytterbium,	Yttrium.

Certain chemical reactions for a long time made me dismiss yttrium from the first list of likely bodies. In my analysis of zircons, towards the latter part of the process, I used the following process to separate the iron: The solution mixed with tartaric acid and excess of ammonia was allowed to stand for some time. A small quantity of a precipitate gradually formed, which was filtered off, and it was this filtrate, after separating the iron with ammonic sulphide, that yielded the greatest quantity of substance giving the citron band. Now one of the methods of separating yttria from alumina, berylla, thoria, and zirconia is to precipitate it as tartrate in the presence of excesses of ammonia, the other earths remaining in solution. Fresenius says: "The precipitation ensues only after some time, but it is complete."

The precipitate thus obtained with tartaric acid and ammonia, should therefore contain all the yttria—*it gave no citron band whatever in the radiant matter tube;* whilst the residue, which should be free from yttria, proved for a long time the only source of material wherewith to investigate the chemical properties of the body giving the citron spectrum.

Another reason which made me, at this stage of the research, pass over yttria, was that I had already tested this earth in the radiant matter tube. In a paper on "Discontinuous Phosphorescent Spectra in High Vacua," read before the Royal Society, May 19, 1881, I said: "Yttria shows a dull greenish light giving a continuous spectrum."

For these reasons I for a long time omitted yttria from my list of possible bodies, and considered that the earth, if not a new one, might turn out to be either mosandra, terbia, or ytterbia.

About 15 lbs. weight of samarskite was worked up, partly by the hydrofluoric acid method of Lawrence Smith, and partly by fusion with potassic bisulphate.

These methods both gave as a result a large quantity of mixed earths containing most, if not all, the bodies enumerated in the foregoing list. Tested in the radiant matter tube this mixture gave the citron spectrum very brilliantly.

These earths were treated by a series of chemical processes too long

and complicated to describe in this abstract, and the result of about five hundred fractional precipitations gave me a mixture of earths having an H equivalent, M=48, and showing a strong absorption spectrum; a mixture having an H equivalent, M=33, having no absorption spectrum; and intermediate earths.

In the radiant matter tube all these fractions gave the citron band spectrum well, but that of the earth of lowest equivalent was much the brightest, and that of the highest equivalent the least intense.

Three methods are available for the partial separation of these earths, and for the complete purification of any one of them. The formic acid process is best for separating terbia, as terbic formate is difficultly soluble in water, the other formates being easibly soluble.

Fractional precipitation with oxalic acid separates first erbia, holmia and thulia, then terbia, and lastly yttria. This is the only method which is applicable for the separation of small quantities of terbia from yttria.

Fusing the nitrates separates ytterbia, erbia, holmia and thulia from yttria. It is not so applicable when terbia is present, and is most useful in purifying the gadolinite earths. This process is the only one known for separating ytterbia from yttria.

Selection must be made of these methods according to the mixture of earths under treatment, changing the method as one earth or the other becomes concentrated on one side or thrown out on the other. Each operation must be repeated many times before even approximate purity is attained. The operations are more analogous to the separation of members of homologous series of hydrocarbons by fractional distillation than to the separations in mineral chemistry as ordinarily adopted in the laboratory.

Pure terbia ignited with sulphuric acid and tested in the radiant matter tube shows no citron band spectrum.

A concentrated solution of the purest terbia obtained in this way, when examined by the spectroscope, showed no absorption lines whatever—proving the absence of erbium, holmium and thulium.

I did not attempt any separation of erbium, holmium and thulium from each other, as the evidence obtained was sufficient to show that the element giving the citron band spectrum was not one of these three metals. Likewise I had far too little material to enable me to enter on a work of such difficulty with any prospect of success.

The chemical characters of mosandra are so little known that I could

not attempt to search for it. But as the citron band-forming earth always appeared concentrated amongst those whose double sulphates were most soluble in potassic sulphate,—and, of these, amongst those having the palest color and the lowest atomic weight,—it was scarcely conceivable that the earth I was in search of should ultimately prove to be one whose properties did not in any case correspond to these,—of a dark orange yellow color, forming a difficultly soluble double potassic sulphate, and having the very high equivalent of M=51·2; these being the properties ascribed to mosandra by the discoverer, Professor Lawrence Smith.

Ytterbia was prepared from gadolinite, as this mineral is said by Nilson to contain most ytterbia. It was separated from accompanying earths by processes described in the paper. The resulting earth gave at first a faint citron band spectrum, evidently due to impurity; on repeating the purification several times I at last succeeded in obtaining a white earth which gave only the merest trace of citron band spectrum. Its hydrogen equivalent, 58·0, and its chemical properties showed that it was probably Marignac's ytterbia. Subsequent experiments satisfied me that this earth did not contain more than 1-10,000th part of yttria. The extreme tediousness of the chemical operations necessary to obtain this high degree of purity, and the long time they required, prevented me from pushing these results beyond what was necessary to prove the special point at issue.

The yttria, purified as already described, might still contain traces of terbia, together with erbia, holmia and thulia. These were gradually removed by the fusing nitrate process. The atomic weight gradually got down to 31·0, but the spectra did not vary very much; that from the earth of lowest atomic weight being, however, the most brilliant.

Pure yttria is quite white. That from gadolinite on testing in the radiant matter tube gave a spectrum absolutely identical with that given by the zircon, cerite, thorite orangite, and samarskite yttria. Pure yttria was also prepared from yttro-tantalite, euxenite, tyrite, and also from plaster of Paris and common limestone. In no case could I detect any difference in the position or intensity of the lines shown by their phosphorescent spectra.

THE PHOSPHORESCENT SPECTRUM OF YTTRIA.

The spectrum shown by pure ignited yttric sulphate in a radiant matter tube is one of the most beautiful objects in the whole range of

spectroscopy. The spectrum is best seen under low dispersion and not too narrow a slit. It consists essentially of a broad red band, an intensely brilliant citron band, and two almost equally brilliant green bands. Other fainter lines are also seen, but they are not characteristic. Colored drawings and maps of the spectrum to scale accompany the paper. This description applies to the spectrum shown either by pure yttric sulphate or by an earth tolerably rich in yttria. When traces are present, the citron band only is seen. A little more yttria brings out the first and then the second green band, and finally, as the proportion of yttria increases, the red and blue bands appear.

The paper next gives a description of experiments made with pure yttria, and with various compounds of it, to see which would give the most characteristic spectrum. The sulphate heated to redness was found to give the best results. Pure yttria precipitated by ammonia did not phosphoresce in the slightest degree, and, necessarily, no citron band spectrum was to be seen. The yttria was removed from the tube, converted into sulphate, heated to redness, and again tested. This time it gave the citron band magnificently. This shows what apparently trivial circumstances will alter the whole course of an investigation. In 1881, when searching for discontinuous phosphorescent spectra, I tried a similar experiment with pure precipitated yttria, and entirely missed its citron band spectrum. Had I first treated the yttria with sulphuric acid instead of testing the earth itself in the radiant matter tube the results would have been very different, and this research would probably have never been undertaken.

Yttria was now prepared by igniting the precipitated oxalate at a red heat. On testing it in the radiant matter tube it phosphoresced with feeble intensity, the light being about one-twentieth of that given by the ignited sulphate under similar conditions. The citron band was almost as sharp as the sodium line, and was shifted one division towards the blue end. The two green bands were visible, but very hazy and indistinct, and only to be resolved into bands with difficulty.

It is an old and probably a true saying that every element could be detected everywhere had we sufficiently delicate tests for it. Early observations had prepared me for the wide distribution of yttrium, and no sooner had the exquisite sensitiveness of this spectrum test forced itself on my notice than I sought for yttrium in other minerals. The facts which I had noticed in connection with the variation of the appearance of the citron spectrum, according to the quantity of yttrium pres-

ent, showed that it might be possible to devise a process for the rough quantitative estimation of yttrium, and after several experiments a spectrum test was devised sufficiently delicate to detect one-millionth part of yttria in a mineral. A table is given showing the results of this quantitative spectrum analysis, from which it is seen that amongst other substances pink coral contains one part of yttrium in 200 parts; strontianite, one part of yttrium in 500 parts; chondrodite, from Mount Somma, one part in 4,000; calcite, one part in 10,000; ox bone, one part in 10,000; an earthy meteorite (Alfianello), one part in 100,000, and tobacco ash, one part in 1,000,000.

THE CAUSE OF EVIDENT MAGNETISM IN IRON, STEEL, AND OTHER MAGNETIC METALS.*

By Professor D. E. Hughes, F.R.S.

The extreme sensitiveness of the induction balance to all molecular changes in the structure of metals was remarked in my first paper on this subject to the Royal Society;† and in the case of iron and steel it is most remarkable, as the addition or substraction of $\frac{1}{500000}$ part, or the addition of the smallest iron filing to an already large balanced mass of iron, is at once rendered evident and measurable. Possessing such an invaluable instrument of research, I was desirous of investigating the molecular construction of iron and steel, but at once I met with a difficulty, viz., that magnetism itself completely changed the character of any piece of iron under investigation. Consequently, finding no help or explanation of the effects produced from any accepted theories of magnetism, I was forced to investigate, by means of the induction balance, the whole question of magnetism as existing in the interior of a magnet, and to determine the particular structure for each case, such as neutrality and polarity. In a recent paper to the Royal Society, upon the theory of magnetism,‡ I described the use of and demonstrations obtained by the induction balance. In this paper I propose to confine myself to demonstrations that can be repeated

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*Read before the Society of Telegraph Engineers and of Electricians, May 24, 1883.

†"On an Induction Current Balance and Experimental Researches made therewith."—*Proceedings Royal Society*, March 29, p. 56, 1879.

‡*Proceedings Royal Society*, May 10, 1883.

without it, and whose effects can be observed by the aid of ordinary magnetic direction needles. That magnetism is of a molecular nature has long been accepted, for it is evident that, no matter how much we divide a magnet, we still have its two poles in each separate portion, consequently we can easily imagine this division carried so far that we should at last arrive at the molecule itself possessing its two distinctive poles, consequently all theories of magnetism attempt some explanation of the cause of this molecular polarity, and the reason for apparent neutrality in a mass of iron. Couloumb and Poisson assume that each molecule is a sphere containing two distinct magnetic fluids, which in the state of neutrality are mixed together, but when polarized are separated from each other at opposite sides; and, in order to explain why these fluids are kept apart as in a permanent magnet, they had to assume, again, that each molecule contained a peculiar coercive force, whose functions were to prevent any change or mixing of these fluids when separated.

There is not one experimental evidence to prove the truth of this assumption; and as regards coercive force, we have direct experimental proof opposing this view, as we know that molecular rigidity or hardness, as in tempered steel, and molecular freedom or softness, as in soft iron, fulfill all the conditions of this assumed coercive force. Ampère's theory, based upon the analogy of electric currents, supposes elementary currents flowing around each molecule, and that in the neutral state these molecules are arranged haphazard in all directions, but that magnetization consists in arranging them symmetrically. The objections to Ampère's theory are numerous. 1st. We have no knowledge or experimental proof of any elementary electric currents continually flowing without any expenditure of energy. 2d. If we admit the assumption of electric currents around each molecule, the molecule itself would then be electro-magnetic, and the question still remains, what is polarity? Have the supposed electric currents separated the two assumed magnetic fluids contained in the molecule, as in Poisson's theory? or are the electric currents themselves magnetic, independent of the iron molecule? In order to produce the supposed heterogeneous arrangement of neutrality, Ampére's currents would have either to change their position upon the molecule, and have no fixed axis of rotation, or else the molecule, with its currents and polarities, would rotate, and thus be acting in accordance with the theory of De la Rive. 3d. This theory does not explain why (as in the case of soft

iron) polarity should disappear whenever the exciting cause is removed, as in the case of transient magnetization. It would thus require a coercive force in iron to cause exactly one-half of the molecules to instantly reverse their direction, in order to pass from apparent external polarity to that of neutrality. The influence of mechanical vibrations and stress upon iron in facilitating or discharging its magnetism, as proved by Matteucci, 1847, in addition to the discovery by Page, 1837, of a molecular movement taking place in iron during its magnetization, producing audible sounds, and the discovery by Dr. Joule, 1842, of the elongation of iron when magnetized, led De la Rive, in his remarkable *Treatise on Electricity*, 1853, to give his theoretical views upon magnetism in the following remarkable words: "The whole of the magnetic molecular phenomena that we have been studying lead us to believe that the magnetization of a body is due to a particular arrangement of its molecules, originally endowed with magnetic virtue, but which in the natural state are so arranged that the magnetism of the body that they constitute is not apparent. Magnetism would, therefore, consist in disturbing this state of equilibrium, or in giving to the particles an arrangement that makes manifest the property with which they are endowed, and not in developing it in them. The coercitive force should be the resistance of the molecules to change their relative positions."

Wiedermann, in 1861, gives a theory in which he admits the fluids of Poisson, or the elementary currents of Ampère, as the cause of polarity of the molecule, but believes that the molecules are turned in a general direction in the case of polarity, and that in neutrality, like Ampère's, the magnetic axes of the molecules are turned in all directions. Maxwell, in his remarkable treatise on "Electricity and Magnetism," 1881, page 75, gives the following résumé of Weber's theory: "Weber's theory differs from Poisson's in assuming that the molecules of the iron are always magnets, even before the application of the magnetising force, but that in ordinary iron the magnetic axes of the molecules are turned indifferently in every direction, so that the iron, as a whole, exhibits no magnetic properties." And again, page 429, Maxwell says he agrees with Weber's views, and that neutrality, or unmagnetized iron, has the axes of its molecules placed indifferently in all directions, and that the act of magnetization consists in turning all the molecules so that their axes are either rendered all parallel to one direction, or at least deflected in that direction. I have quoted these

several theories which admit of the inherent polarity of the molecule, and in that respect they entirely agree with my own; but the induction balance at once shows that they are erroneous in the most important part, for my researches have proved that neutrality is perfectly symmetrical, that there is no case of neutrality where the axes of the molecules are turned indifferently in all directions, and that we cannot obtain perfect neutrality except when the molecules form a complete closed circuit of attraction. I believe that a true theory of magnetism should admit of complete demonstration, that it should present no anomalies, and that all the known effects should at once be explained by it. From numerous researches I have gradually formed a theory of magnetism entirely based upon experimental results, and these have led me to the following conclusions:

1. That each molecule of a piece of iron, steel, or other magnetic metal is a separate and independent magnet, having its two poles and distribution of magnetic polarity exactly the same as its total evident magnetism when noticed upon a steel bar-magnet.

2. That each molecule, or its polarity, can be rotated in either direction upon its axis by torsion, stress, or by physical forces such as magnetism and electricity.

3. That the inherent polarity or magnetism of each molecule is a constant quantity like gravity; that it can neither be augmented nor destroyed.

4. That when we have external neutrality, or no apparent magnetism, the molecules, or their polarities, arrange themselves so as to satisfy their mutual attraction by the shortest path, and thus form a complete closed circuit of attraction.

5. That when magnetism becomes evident, the molecules or their polarities have all rotated symmetrically in a given direction, producing a north pole if rotated in that direction as regards the piece of steel, or a south pole if rotated in the opposite direction. Also, that in evident magnetism, we have still a symmetrical arrangement, but one whose circles of attraction are not completed except through an external armature joining both poles.

6. That we have permanent magnetism when the molecular rigidity, as in tempered steel, retains them in a given direction, and transient magnetism whenever the molecules rotate in comparative freedom, as in soft iron.

EXPERIMENTAL EVIDENCES.

In the above theory the coercive force of Poisson is replaced by molecular rigidity and freedom; and as the effects of mechanical vibrations, torsion, and stress upon the apparent destruction and facilitation of magnetism is well known, I will, before demonstrating the more serious parts of the theory, cite a few experiments to prove that molecular rigidity fulfils all the requirements of an assumed coercive force. The influence of vibrations, torsion, or stress of any kind upon a magnetized steel or iron rod may be seen by striking with a wooden mallet rods of hard and soft steel, also hard and soft iron previously magnetized to a known degree. The tempered steel, owing to its molecular rigidity, will lose but 5 per cent., the soft steel 60, hard iron 50, and soft Sweedish iron 99 per cent. of its magnetism, the amount of loss depending not so much upon whether the metal be steel or iron as upon its degree of hardness and softness; and as hard steel requires far more power to magnetize it to the same force than iron, it is possible to imagine a steel so hard that its molecules could not rotate, and that, consequently, no magnetism could be manifested from a given inducing cause, whilst a perfectly soft iron would give the maximum effect, and instantly return to its previous state. From this we might in error suppose that soft Swedish iron could not retain its magnetism, and that its natural state would be zero, or neutrality. The apparent disappearance of magnetism, however, is here due to the extreme freedom of motion of its molecules allowing them at once to follow the comparatively feeble directing force of the earth's magnetism. We can demonstrate this by feebly magnetizing a rod of soft iron held vertically, so that its north pole is at the lower portion. Upon removing the inducing magnet, or electro-magnetic coil, we find that the rod retains a powerful north polarity; but if magnetized in a contrary sense, then we have only *traces* of magnetism left upon the withdrawal of the inducing cause. To succeed in this experiment, as in all others where soft iron is mentioned, we should use the best Swedish charcoal iron, thoroughly annealed at high temperature. We find, again, that rods of steel or iron will lose far less magnetism when vibrated in the magnetic dip, or vertically, when their north poles are at the lowest extremity, than when horizontal, or still less than when their poles are contrary to those of the earth's field, and also that they will acquire their maximum magnetism from a given exciting cause when held vertically as described, and the molecules allowed greater freedom of

motion to obey the directing influence by vibrations, torsion, stress, or blows upon the iron. Any influence that would tend to give greater freedom of motion, such as heat or mechanical trepidations, gives a far higher magnetic force to the iron than could be obtained without these aids.

In order to render visible the effects of motion upon magnetism, we may take two glass tubes, or ordinary vials, of any length or diameter, say 10 centimetres in length by 2 centimetres in diameter. If we now put iron filings in these tubes, leaving about one-third vacant, so as to allow complete freedom in the filings when shaken, we find that each tube, when magnetized, retains an equal amount of residual magnetism, and that this all disappears upon slightly shaking the tube. We are thus imitating the effects of vibration. But if in one of these tubes we pour melted resin (in fact, any slightly viscous liquid, such as petroleum suffices), we then render these filings more rigid, and then we can no longer produce by shaking the disappearance of its residual magnetism. In pouring in petroleum we have apparently been introducing a strong coercitive force, but we know that it can only have the mechanical effect of rendering the iron filings less free to turn, and so comparatively rigid. If we desire to see the effect of torsion, we have only to shake the filings so that when the tube is held horizontally the vacant space is above, and rotate it slightly (but without shaking) about a horizontal axis. Its remaining magnetism instantly disappears upon rotation, although we evidently have not changed the longitudinal position of its particles. A similar effect takes place upon a soft iron rod; for if we magnetize it, and observe its remaining magnetism, we find that, upon giving a slight torsion to this wire, its remaining magnetism instantly disappears—a similar effect to that in the rotating tube of iron filings. But if the iron is rendered more rigid by hammering, or steel rendered hard and rigid by tempering, torsions or vibrations have but little effect, as in the case of the filings rendered rigid as above mentioned. Thus we have no longer need of an assumed mysterious coercitive force to account for the retention of magnetism; for once knowing the mechanical qualities of iron and steel, and their degree of molecular rigidity or hardness, we can at once predict their retentive magnetic powers.*

* "On the Molecular Rigidity of Tempered Steel," by Professor D. E. Hughes, F.R.S.—*Proceedings Institution of Mechanical Engineers*, pages 72-79, January, 1883.

ROTATION OF INHERENT POLARIZED MOLECULES.

Torsion, as well as mechanical vibrations, has, as we have seen, a powerful influence in aiding the molecules to overcome their inertia, and thus aid them to rotate in the direction of the inducing influence; and we may thus polarize strongly a flat soft iron rod by simply bending or vibrating it when held vertically, and if we measure the magnetic force obtained, we shall notice that the force is strictly relative to the degree of softness of the iron. Thus with hard steel we should obtain only traces of polarization, whilst with extremely pure soft Swedish iron we obtain the maximum of force. The bar of iron or steel, being held in the earth's magnetic field, of infinite size compared with the bar, and infinitely homogeneous, cannot deflect or weaken its surrounding field. Its lower portion being north, apparently strengthens it by its reaction, whilst its upper, south, apparently weakens the field; but, as Maxwell has shown, "the two poles of each molecule are equal and opposite; consequently, the sum of each molecule and the whole mass must be zero." We have a far greater induced polarity in iron or steel when the iron is in thin bars or small wires, and this we should expect, as the external molecules rotate directly under the influence of the earth's magnetism, whilst those forming the interior of the bar either rotate feebly, or, as in the case of very thick bars, actually act as an armature, preventing, by their influence, free rotation of the exterior molecules. Thus, as the sum of the two and equal polarities in a bar of iron is zero, it is evident that its polarity must be inherent. I have some remarkably pure soft Swedish iron wire, one millimetre in diameter, and as its inherent polar force seemed great when held vertically in the earth's magnetic field, I measured in the induction balance this force compared with a similar column of the magnetic atmosphere which it displaced. The inherent polarity of this wire, simply rendered evident by the earth's magnetism, was 15,600 times greater than the column it displaced. We cannot, either by induction, conduction, or concentration, produce a greater force in another body of similar displacement or size, otherwise we could easily create power from a feeble source. Thus the enormously greater magnetic power observed in iron than the same column of air which it displaces must be due to the inherent polarity of its molecules.

Amongst numerous bars of iron upon which I have experimented, one of ordinary hoop-iron, 2 centimetres wide, 40 centimetres long, and $1\frac{1}{2}$ millimetre thick, not softened, possesses sufficient molecular

rigidity to be apparently uninfluenced by earth's magnetism. When this rod is rendered neutral, we have but feeble polarity—mere traces when it is held vertically under the earth's magnetic influence; but if we apply a few successive torsions or vibrations to it when thus held, we have at once several thousand times greater polarity than before. Now, if iron had the power of deflecting or concentrating the earth's magnetism upon itself, it should not require the mechanical aid to molecular rotation given to it by these torsions or vibratoins. Thus we are forced to conclude at least the existence of the inherent polarity of the molecules; and, if we admit this, we must also, as a necessary consequence, admit the rotation of these molecules, else we cannot explain why mechanical vibrations allowing freedom of motion should always produce the polarity in accordance with the directing cause. I have already shown that torsion and vibrations *per se* are apparently destructive of magnetism; consequently in this case Poisson's two fluids and Ampère's parallel currents should, according to their theory, be mixed or heterogeneous, whilst according to the views I am sustaining the polarized molecules should obey, as compass needles, any magnetic directing cause whenever sufficient molecular freedom of motion allows free rotation. The inherent polarity of iron may again be observed by drawing a flat rod of soft iron over one or both poles of a permanent magnet. This rod will then be powerfully magnetized, its remaining magnetism, when separated from the magnet, being sufficiently powerful to strongly deflect a suspended direction needle. A few slight torsions or vibrations will then completely discharge it. Now, suppose this operation repeated successively many thousand times, if there was no inherent polarity we should have gradually drawn all the polarity out of the magnet, and discharged it into the atmosphere. Nothing of the kind takes place. The molecules of the iron are simply rotated each time, and the only energy in work expended or lost comes from the arm of the experimenter, and the energy required would be strictly in accordance with the molecular freedom, or softness and hardness of the iron and steel; thus, whilst soft iron could be easily polarized and discharged by mechanical torsions, hard-tempered steel would require a far greater amount. Dr. Warren De La Rue, F.R.S., kindly aided me in this part of the research by passing a current from his well-known chloride of silver battery through iron and steel wires. A condenser of 42·8 microfarad capacity, charged by 3360 cells, was used. We passed this enormous electric charge

longitudinally through the wires, and observations were made as to whether any change whatever was produced in their quality or inherent polarity, the result being that these wires gave exactly the same magnetic polarity from a givin directing or inducing cause as before, being similar in nature and degree, consequently this enormous electric force had not changed or destroyed the original inherent polarity. If the molecules possess inherent polarity and rotate upon their axes, similar to a series of compass needles having a slight degree of frictional rigidity, then, upon passing one pole of a magnet above them, they would turn symmetrically in one direction, and drawing the same pole of the magnet in the contrary direction would rotate them, and they would then remain symmetrically in the opposite direction.

A precisely similar effect takes place in a soft iron rod placed east and west a few inches above a direction needle. Upon drawing the south pole of a powerful natural magnet at a few centimetres distance above the wire from east to west, the north polarities of the molecules successively turn in the direction of west, following the attraction of the south pole, as previously seen on the small compass needles. The rod is now magnetized with its north pole west, as indicated by the direction needle below any portion of this rod. Upon passing the same south pole of the natural magnet in a contrary direction, the molecules all rotate, their north poles still turning successively to the south pole of the permanent magnet until its arrival at the end from which the first magnetization commenced. The rod has now entirely changed its polarity, and its north pole is east. This phenomenon is well known in the ordinary magnetization of rods, where care is taken to draw the magnet always in a similar direction, or the poles would be reversed at each to and fro drawing. To account for this, on Coulomb-Poisson's theory, it would be requisite that, first, all the fluids be separated with their north fluids symmetrically in one direction, but on drawing back the magnet, these fluids would have to mix together, the north fluid passing through its south fluid to be finally opposite to its previous position, its coercive force doing the double work of allowing both fluids to mix and pass through each other, and finally keeping them entirely apart. Ampère's theory would require that from a haphazard arrangement the molecules should become symmetrically arranged upon the first passage of the magnet, then upon its reversed direction one half of the electric elementary currents should successively revolve in a contrary direction to arrive at neutrality before,

finally, the other half followed the direction of the first half, and now all these currents would be revolving in the opposite direction to that upon the first magnetization. We thus see that both these theories, whilst resting altogether upon assumption, are extremely complicated and improbable. We might suppose, from the theory which I am advocating, that upon the rotation of the molecules there would be some disturbance or mechanical trepidation; and such is found to be the case, as first observed by Page, and afterwards verified by Dr. Joule and De la Rive, in the molecular sounds produced in iron upon its magnetization. Reis's first telephone was founded upon these sounds, and Du Moncel has made numerous researches upon this subject. In the last of my experiments cited, the sounds are too feeble to be heard, but by the application of the microphone these trepidations at once become audible.

That molecules of iron and other metals rotate with time, whose period becomes shortened by mechanical vibrations, is well known in metallurgy, the ultimate result being generally the passage from a fibrous condition, as in iron wires, to a high degree of crystallization. For many years I employed a circular vibrating spring as the regulator of speed of my printing telegraph instrument, and although this spring was so regulated by means of a frictional break, or "Frein," as not to surpass its limits of elasticity, these springs were constantly breaking after a few days' use, and, as a matter of urgent necessity, I made special researches into the cause of this breaking after a few days' constant vibratory action. I found at the point of rupture a high state of crystallization. Fibrous iron would thus become thoroughly crystallized and break in one day; the number of vibrations for an instrument in constant use during twenty-four hours being 1,209,600. Thus we could roughly estimate the life of iron in the form of one of these springs at one million vibrations. Copper crystallized in one hour, and all metals and alloys were inferior to steel, except aluminium bronze. The latter springs would stand six weeks' constant use, or some fifty millions of vibrations. I finally resolved this problem by spreading the amount of vibrating work over a spiral spring containing 3 metres of steel rod wound into the same space as previously held by the straight rod of 30 centimetres. By this means the average life of these springs has become five years. Evidently the molecules of these fibrous springs must have rotated under the vibrations, in order to produce crystals. The same phenomenon is observed in axles of

carriages receiving constant trepidations, large crystals being always found at the point of fracture. Again, if we rapidly magnetize and demagnetize an iron rod, we have the production of evident heat, due to the constant motion of its molecules. Maxwell describes an experiment of Beetz, in which an exceedingly small filament of iron was deposited by electrotype, under the influence of a strong magnetic field, in order to arrive at the inherent polarity of comparatively few molecules, and, as its magnetic force was very great, he regards the experiment as conclusive. My own experiments show that we have far less external magnetic force from a solid bar than from a thin tube or flat bar of the same surface exposed to a limited exciting cause. We know that magnetism does not penetrate to a very great depth, and we also know that, if to a thin steel permanent magnet we place another piece unmagnetized, or, better still, a rod of soft iron, its external polarity is greatly reduced; consequently the external evidence of polarity is not a direct measure of the degree of rotation, nor of the total inherent polarity of its mass; We may have a great superficial *external* rotation superposed upon rotations of an opposite nature, as will be seen later; and thus the internal molecules of a magnet often act more or less as an external armature in closing its circle of attractions.

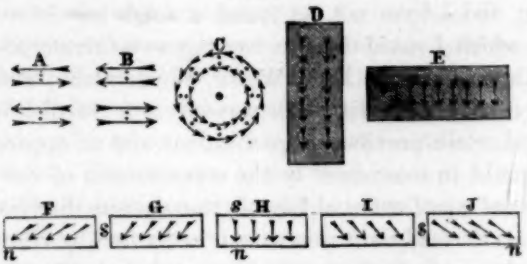
I have stated my belief that the molecule itself possesses its inherent polarity, which, like gravity, is an endowed quality for which we have no more reason to suspect the cause to be elementary electric currents than that elementary currents should be the cause of gravity, chemical affinity, or cohesion and its polar power of crystallization, most of which are effected by an electric current. We have a certain analogy between electric currents and magnetism, but not so great as the analogy between the magnetic polarity of a molecule and its other endowed qualities. Magnetism, like chemical affinity, cohesion, and crystallization, has its critical points. Faraday discovered that at red-yellow heat iron instantly lost its apparent polar magnetic power, to be as instantly restored at red heat, the critical point varying in iron, steel, etc., and being the lowest in nickel. This would be difficult to explain upon Ampère's theory, as we should have to admit the instant destruction or cessation of the elementary currents, to be again restored at a few degrees less temperature. It would be equally difficult to explain under my view, if it did not belong to a whole class of phenomena due to the possession by the molecules of various endowed qualities, of which chemistry and all our means of research can only teach us their

critical points, without attempting to explain why, for instance, iron has a greater affinity for oxygen than gold. We know that it is so; we know that the molecules of all matter are endowed with certain qualities having certain critical points, and I can see no reason for separating their magnetic inherent polarity from their numerous other qualities.

NEUTRALITY.

The apparatus needed for researches upon evident external polarity requires no very great skill or thought, but simply an apparatus to measure correctly the force of the evident repulsion or attraction; in the case of neutrality, however, the external polarity disappears, and we consequently require special apparatus, together with the utmost care and reflection in its use. From numerous researches previously made by means of the induction balance, the results of which I have

FIG. 1.



already published, I felt convinced that in investigating the cause of magnetism and neutrality I should have in it the aid of the most powerful instrument of research ever brought to bear upon the molecular construction of iron, as indeed of all metals. It neglects all forces which do not produce a change in the molecular structure, and enables us to penetrate at once to the interior of a magnet or piece of iron, observing only its peculiar structure and the change which takes place during magnetization or apparent neutrality. The induction balance is effected by three distinct arrangements of molecular structure in iron and steel, by means of which we have apparent external neutrality.

Fig. 1 shows several polar directions of the molecules as indicated by the arrows. Poisson assumed, as a necessity of his theory, that a molecule is spherical, but Dr. Joule's experimental proof of the elongation of iron by $\frac{1}{720000}$ of its length when magnetized proves at least that its form is not spherical; and, as I am unable at present to demon-

strate my own views as to its exact form, I have simply indicated its polar direction by arrows—the dotted oval lines merely indicating its limits of free elastic rotation. In Fig. 1, at A, we have neutrality by the mutual attraction of each pair of molecules, being the shortest path in which they could satisfy their mutual attractions. At B we have the case of superposed magnetism of equal external value, rendering the wire or rod apparently neutral, although a lower series of molecules are rotated in the opposite direction to the upper series, giving to the rod opposite and equal polarities. At C we have the molecules arranged in a circular chain around the axis of a wire or rod through which an electric current has passed. At D we have the evident polarity induced by the earth's directive influence when a soft iron rod is held in the magnetic meridian. At E we have a longitudinal neutrality produced in the same rod when placed magnetic west, the polarity in the latter case being transversal. In all these cases we have a perfectly symmetrical arrangement, and I have not yet found a single case in well-annealed soft iron in which I could detect a heterogeneous arrangement, as supposed by Ampère, De la Rive, Weber, Wiedermann, and Maxwell. We can only study neutrality with perfectly soft Swedish iron. Hard iron and steel retain previous magnetizations, and an apparent external neutrality would in most cases be the superposition of one magnetism upon another of equal external force in the opposite direction, as shown at B, Fig. 1. Perfectly soft iron we can easily free, by vibrations, from the slightest trace of previous magnetism, and study the neutrality produced under varying conditions.

If we take a flat bar of soft iron, of 30 or more centimetres in length, and hold it vertically (giving while thus held a few torsions, vibrations, or better still, a few slight blows with a wooden mallet, in order to allow its molecules to rotate with perfect freedom), we find its lower end to be of strong north polarity, and its upper end south. On reversing the rod and repeating the vibrations, we find that its lower end has precisely a similar north polarity. Thus the iron is homogeneous, and its polarity symmetrical. If we now magnetize this rod to produce a strong south pole at its lower portion, we can gradually reverse this polarity, by the influence of earth's magnetism, by slightly tapping the upper extremity with a small wooden mallet. If we observe this rod by means of a direction needle at all parts, and successively during its gradual passage from one polarity to the other, there will be no sudden break into a haphazard arrangement, but a

gradual and perfectly symmetrical rotation from one direction to that of the opposite polarity. If this rod is placed east and west, having first, say, a north polarity to the right, we can gradually discharge or rotate the molecules to zero, and as gradually reverse the polarity by simply inclining the rod, so as to be slightly influenced by earth's magnetism; and at no portion of this passage from one polarity to neutrality, and to that of the opposite name, will there be found a break of continuity of rotation or haphazard arrangement. If we rotate this rod slowly, horizontally or vertically, taking observations at each few degrees of rotation of an entire revolution, we find still the same gradual symmetrical change of polarity, and that its symmetry is as complete at neutrality as in evident polarity.

In all these cases there is no complete neutrality, the longitudinal polarity simply becoming transversal when the rod is east and west. F, G, H, I, J, Fig. 1, show this gradual change, H being neutral longitudinally, but polarized transversely. If, in place of the rod, we take a small square soft iron plate and allow its molecules freedom under the sole influence of the earth's magnetism, then we invariably find the polarity in the direction of the magnetic dip, no matter in what position it be held, and a sphere of soft iron could only be polarized in a similar direction. Thus we can never obtain complete external neutrality whilst the molecules have freedom and do not form an internal closed circle of mutual attractions; and, whatever theory we may adopt as to the cause of polarity in the molecule, such as Coulomb's Poisson's, Ampère's, there can exist no haphazard arrangement in perfectly soft iron, as long as it is free from all external causes except the influence of the earth; consequently these theories are wrong in one of their most essential parts. We can, however, produce a closed circle of mutual attractions in iron and steel, producing complete neutrality as long as the structure is not destroyed by some stronger external directing influence. Oersted discovered that an external magnetic needle places itself perpendicular to an electric current; and we should expect that, if the molecules of an iron wire possessed inherent polarity and could rotate, a similar effect would take place in the interior of the wire to that observed by Oersted. Wiedermann first remarked this effect, and it has been known as circular magnetism. This circle, however, consists really in each molecule having placed itself perpendicular to the current, simply obeying Oersted's law, and thus forming a complete circle in which the mutual attractions of the molecules forming

that circle are satisfied, as shown at C, Fig. 1. This wire becomes completely neutral, any previous symmetrical arrangement of polarity rotating to form its complete circle of attractions; and we can thus form in hard iron and steel a neutrality extremely difficult to break up or destroy. We have evident proof that this neutrality consists of a closed chain, or circle, as by torsion we can partially deflect them on either side; thus from a perfect externally neutral wire, producing either polarity, by simple mechanical angular displacement of the molecules as by right or left-handed torsion. If we magnetize a wire placed east and west it will retain this polarity until freed by vibrations, as already remarked. If we pass an electric current through this magnetised wire, we can notice the gradual rotation of the molecules, and the formation of the circular neutrality. If we commence with a weak current, gradually increasing its strength, we can rotate them, as slowly as may be desired. There is no sudden break or haphazard moment of neutrality; the movements to perfect zero are accomplished with perfect symmetry throughout.

We can produce a more perfect and shorter circle of attractions by the superposition of magnetism, as at B, Fig. 1. If we magnetize a piece of steel or iron in a given direction with a strong magnetic directing power, the magnetism penetrates to a certain depth. If we slightly diminish the magnetising power, and magnetize the rod in a contrary direction, we may reduce it to zero, by the superposition of an exterior magnetism upon one of a contrary name existing at a greater depth; and if we continue this operation, gradually diminishing the force at each reversal, we can easily superpose ten or more distinct symmetrical arrangements, and, as their mutual attractions are satisfied in a shorter circle than in that produced by electricity, it is extremely difficult to destroy this formation when once produced. The induction balance affords also some reasons for believing that the molecules not only form a closed circle of attractions, as at B, but that they can mutually react upon each other, so as to close a circle of attractions as a double molecule, as shown at A. The experimental evidence, however, is not sufficient to dwell on this point, as the neutrality obtained by superposition is somewhat similar in its external effects. We can produce a perfectly symmetrical closed circle of attractions of the nature of the neutrality of C, Fig. 1, by forming a steel wire into a closed circle, 10 centimetres in diameter, if this wire is well joined at its extremities by twisting and soldering. We can then magnetize this ring by slowly revolving

it at the extremity of one pole of a strong permanent magnet; and, to avoid consequent poles at the part last touching the magnet, we should have a graduating wedge of wood so that whilst revolving it may be gradually removed to greater distance. This wire will then contain no consequent points of external magnetism; it will be found perfectly neutral in all parts of its closed circle. Its neutrality is similar to C, Fig. 1; for if we cut this wire at any point we find extremely strong magnetic polarity, being magnetized by this method to saturation, and having retained (which it will indefinitely) its circle of attractions complete.

I have already shown that soft iron, when its molecules are allowed perfect freedom by vibration, invariably takes the polarity of the external directing influence, such as that of the earth, and it does so even with greater freedom under the influence of heat Manufacturers of electro-magnets for telegraphic instruments are very careful to choose the softest iron and thoroughly anneal it; but very few recognize the importance as regards the position of the iron whilst annealing it under the earth's directing influence. The fact, however, has long since been observed. Dr. Hooke, 1684, remarked that steel or iron was magnetized when heated to redness and placed in the magnetic meridian. I have slightly varied this experiment by heating to redness three similar steel bars, two of which had been previously magnetized to saturation, and placed separately with contrary polarity as regards each other, the third being neutral. Upon cooling, these three bars were found to have identical and similar polarity. Thus the molecules of this most rigid material, cast steel, had become free at red heat, and rotated under the earth's magnetic influence, giving exactly the same force on each; consequently the previous magnetization of two of these bars had neither augmented nor weakened the inherent polarity of their molecules. Soft iron gave under these conditions by far the greatest force, its inherent polarity being greater than that of steel. I have made numerous other experiments bearing upon the question of neutrality, but they all confirm those I have cited, which I consider afford ample evidence of the symmetrical arrangement of neutrality.

SUPERPOSED MAGNETISM.

Knowing that by torsion we can rotate or diminish magnetism, I was anxious to obtain by its means a complete rotation from north polarity to neutrality, and from neutrality to south polarity, or to completely reverse magnetic polarity by a slight right or left torsion. I

have succeeded in doing this, and in obtaining strong reversal of polarities, by superposing one polarity given whilst the rod is under a right elastic torsion with another of the opposite polarity given under a left elastic torsion, the neutral point then being reached when the rod is free from torsion. The rod should be very strongly magnetised under its first or right-hand torsion, so that its interior molecules are rotated, or, in other words, magnetised to saturation; the second magnetization in the contrary sense and torsion should be feebler, so as only to magnetize the surface, or not more than one-half its depth; these can be easily adjusted to each other so as to form a complete polar balance of force, producing, when the rod is free from torsion, the neutrality as shown at B, Fig. 1. The apparatus needed is simply a good compound horse-shoe permanent magnet, 15 centimetres long, having six or more plates, giving it a total thickness of at least 3 centimetres, We need a sufficiently powerful magnet, as I find that I obtain a more equal distribution of magnetism upon a rod or strip of iron by drawit lengthwise over a single pole in a direction from that pole, as shown in Fig. 2; we can then obtain saturation by repeated drawings, keeping

FIG. 2.

the same molecular symmetry in each experiment. In order to supply a slight elastic torsion when magnetizing rods or wires, I have found it convenient to attach two brass clamp keys to the extremities of the rods, or simply turn the ends at right angles, as shown in the following diagram, by which means we can apply an elastic twist or torsion whilst drawing the rod over the pole of the permanent magnet. We can thus superpose several and opposite symmetrical structures, producing a polar north and south as desired, greatly in excess of that possible under a single or even double magnetization, and by carefully adjusting the proportion of opposing magnetisms, so that both polarities have the same external force, the rod will be at perfect external neutrality when free from torsion.

If we now hold one end of this rod at a few centimetres distance from a magnetic directive needle, we find it perfectly neutral when

free of torsion, but the slightest torsion right or left at once produces violent repulsion or attraction, according to the direction of the torsion given to the rod, the iron rod or strips of hoop-iron which I use for this experiment being able, when at the distance of 5 centimetres from the needle, to turn it instantly 90° on either side of its zero. The external neutrality that we can now produce at will is absolute, as it crosses the line of two contrary polarities, being similar to the zero of my electric sonometer, whose zero is obtained by the crossing of two opposing electric forces. This rod of iron retains its peculiar powers of reversal in a remarkable degree, a condition quite different to that of ordinary magnetization, for the same rod, when magnetised to saturation under a single ordinary magnetism, loses its evident magnetism by a few elastic torsions, as I have already shown; but when it is magnetised under the double torsion with its superposed magnetism, it is but slightly reduced by variations or numerous torsions, and I have found it impossible to render this rod again free from its double polar effects, except by strongly remagnetizing it to saturation with a single polarity. The superposed magnetism then becomes a single directive force, and we can then, by a few vibrations or torsions reduce the rod to its ordinary condition. The effects of superposed magnetism and its double polarity I have produced in a variety of ways, such as by the electro-magnetic influence of coils, or in very soft iron simply by the directive influence of the earth's magnetism, reversing the rod and torsions when held in the magnetic meridian, these rods when placed magnetic west showing distinctly the double polar effects. It is remarkable, also, that we are enabled to superpose and obtain the maximum effects on thin strips of iron from $\frac{1}{4}$ to $\frac{1}{2}$ millimetre in thickness, whilst in thicker rods we have far less effect, being masked by the comparatively neutral state of the interior, the exterior molecules then reacting upon those of the interior, allowing them to complete in the interior their circle of attractions.

I was anxious to obtain wires which would preserve this structure against the destructive influence of torsion and vibrations, so that I could constantly employ the same wires without the comparatively long and tedious process of preparation. Soft irom soon loses the structure, or becomes enfeebled, under the constant to and fro torsions requisite where we desire a constant change of polarity, as described later in the magnetic bells. Hard steel preserves its structure, but its molecular rigidity is so great that we obtain but mere traces of any change of

polarity by torsion. I have found, however, that fine cast steel, untempered, of the kind employed by watch makers, is most suitable; these are generally sold in straight lengths of 30 centimetres. Wires 1 millimetre in diameter should be used, and when it is desired to increase the force, several of these wires—say nine or ten—should be formed into a single rod or bunch. The wire as sold is too rigid to give its maximum of molecular rotation effect. We must, therefore, give it two entire turns or twists to the right, and strongly magnetise it on the north pole of the magnet whilst under torsion. We must again repeat this operation in the contrary direction, after restoring the wire to its previous position, giving now two entire turns to the left, and magnetising it on the south pole. On restoring the wire to its original place, it will be extremely flexible, and we may now superpose several contrary polarities under contrary torsions, as already described. The power of these wires, if properly prepared, is most remarkable, being able to reverse their polarity under torsion, as if they were completely saturated; and they preserve this power indefinitely if not touched by a magnet. It would be extremely difficult to explain the action of the rotative effects obtained in these wires under any other theory than that which I have advanced; and the absolute external neutrality that we obtain in them when the polarities are changing, we know, from their structure, to be perfectly symmetrical. I was anxious to show, upon the reading of this paper, some mechanical movement produced by molecular rotation, consequently I have arranged two bells that are struck alternately by a polarized armature put in motion by the double polarized rod I have already described, but whose position, at 3 centimetres distant from the axis of the armature, remains invariably the same. The magnetic armature consists of a horizontal light steel bar suspended by its central axle; the bells are thin wine glasses, giving a clear musical tone loud enough, by the force with which they are struck, to be clearly heard at some distance. The armature does not strike these alternately by a pendulous movement, as we may easily strike only one continuously, the friction and inertia of the armature causing its movements to be perfectly dead-beat when not driven by some external force, and it is kept in its zero position by a strong directive magnet placed beneath its axis. The mechanical power obtained is extremely evident, and is sufficient to put the sluggish armature in rapid motion, striking the bells six times per second, and with a power sufficient to produce tones loud enough to be clearly

heard in all parts of the hall of the society. As this is the first direct transformation of molecular motion into mechanical movement, I am happy to show it on this occasion. There is nothing remarkable in the bells themselves, as they evidently could be rung if the armature was surrounded by a coil and worked by an electric current from a few cells. The marvel, however, is in the small steel superposed magnetic wire producing by slight elastic torsions from a single wire, 1 millimetre in diameter, sufficient force from mere molecular rotation to entirely replace the coil and electric current.

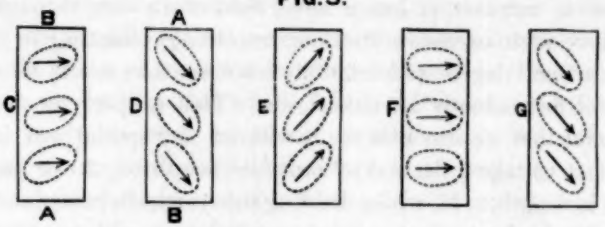
ELASTIC NATURE OF THE ETHER SURROUNDING THE MAGNETIC MOLECULES.

During these researches I have remarked a peculiar property of magnetism, viz., that not only can the molecules be rotated through any degree of arc to its maximum, or saturation, but that, whilst it requires a comparatively strong force to overcome its rigidity or resistance to rotation, it has a small field of its own through which it can move with excessive freedom, trembling, vibrating or rotating through a small degree with infinitely less force than would be required to rotate it permanently on either side. This property is so marked and general that we can observe it without any special iron or apparatus. Let us take a flat rod of ordinary hoop-iron, 30 or more centimetres in length. If, whilst holding this vertically, we give freedom to its molecules by torsions, vibrations. or, better still, by a few blows with a wooden mallet upon its upper extremity, we find, as is well known, that its lower portion is strongly north, and its upper south. If we reverse the rod, we now find it neutral at both extremities. We might here suppose that the earth's directing force had rotated the molecules to zero or transversely, which in reality it has done, but only to the limit of their comparatively free motion ; for if we reverse the rod to its original position, its previous strong polarity reappears at both extremities, thus the central point of its free motion is inclined to the rod, giving by its free motion great symmetrical inclination and polarity in one direction, but when reversed the inclination is reduced to zero.

In Fig. 3, D shows the bar of iron when strongly polarized by earth's magnetic influence under vibrations, with a sufficient force to have rotated its elastic centre of action. C shows the same bar with its molecules at zero, or transversal, the directing force of earth being insufficient without the aid of mechanical vibration to allow them to

change. The dotted lines of D suppose the molecule to be in the centre of its free motion, whilst at C the molecules have rotated to zero, as they are prevented from further rotation by being at the extreme end of its free motion. If, now, we hold the rod vertically, as at C, giving neutrality, and give a few slight blows with a wooden mallet to its upper extremity, we can give just the amount of freedom required for it to produce evident polarity, and we have then equal polarity no matter which end of the bar is below, the centre of its free rotation here being perfect, and the rod perfectly neutral longituinally when held east and west. If, on the other hand, we have given too much freedom by repeated blows of the mallet, its centre of free motion becomes inclined with the molecules, and we arrive at its first condition, except that it is now neutral at D and polarized at C. From this it will be seen that we can adjust this centre of action, by vibrations or blows, to any point within the external directing influence. We can perceive

FIG. 3.



this effect of free rotation in a limited space in all classes of iron and steel, being far greater in soft Swedish iron than in hard iron or steel. A similar phenomenon takes place if we magnetize a rod held vertically in the direction of earth's magnetism. It then gives greater polarity than if magnetized east or west, and if magnetized in a contrary sense to earth's magnetism, it is very feebly magnetized, or, if the rod is perfectly soft, it becomes neutral after strong magnetization. This property of comparative freedom, and the rotation of its centre of action, can be demonstrated in a variety of ways. One remarkable example of it consists in the telephone. All those who are thoroughly acquainted with electro-magnetism, and know that it requires measurable time to charge an electro-magnet to saturation (about $\frac{1}{15}$ of a second for those employed in telegraphy), were surprised that the telephone could follow the slightest change of timbre, requiring almost innumerable changes of force per second. I believe the free rotation

I have spoken of through a limited range explains its remarkable sensitiveness and rapidity of action, and, according to this view it would also explain why loud-sounding telephones can never repeat all the delicacy of timbre that is easily done with those only requiring a force comprised in the critical limits of its free rotation. This property, I have found, has a distinct critical value for each class of iron, and I propose soon to publish researches upon the molecular construction of steel and iron, in which I have made use of this very property as a guide to the quality of the iron itself. The elastic rotation (in a limited space) of a molecule differs entirely from that known as mechanical elasticity. In perfectly soft iron we have feeble *mechanical* elasticity, whilst in tempered steel we have that elasticity at its maximum. The contrary takes place as regards *molecular* elasticity. In tempered steel the molecules are extremely rigid, and in soft iron its molecular elasticity is at its maximum. Its free motion differs entirely from that given it by torsion or stress. We may assume that a molecule is surrounded by continuous ether, more of the nature of a jelly than of that of a gas; in such a medium a molecule might freely vibrate through small arcs, but a rotation extending beyond its critical limit would involve a much greater expenditure of force.

The discovery of this comparatively free rotation of molecules, by means of which, as I have shown, we can (without in any degree disturbing the external mechanical elasticity of the mass) change the axes of their free motion in any direction desired, has led me into a series of researches which have only indirectly any relation with the theory of magnetism. I was extremely desirous, however, of finding an experimental evidence which in itself should demonstrate all portions of the theory, and the following experiment, I believe, answers this purpose. Let us take a square soft iron rod, 5 millemetres in diameter by 30 or more centimetres in length, and force the molecules, by aid of blows from a wooden mallet, as previously described, to have their centres of free motion in one direction; the rod will (as already shown) have polarity at both ends, when held vertically; but if reversed, both ends become completely neutral. If now we turn the rod to its first position, in which it shows strong polarity, and magnetize it whilst held vertically, by drawing the north pole of a sufficiently powerful permanent magnet from its upper to its lower extremity, we find that this rod, instead of having south polarity at its lower portion, as we should expect from the direction of the magnetization, is completely

neutral at both extremities, but if we reverse the rod, its fullest free powers of magnetization now appear in the position where it was previously neutral. Thus, by magnetization, we have completely rotated its free path of action, and find that we can rotate this path as desired in any direction by the application of a sufficient directing power. If we take a rod as described, with its polarities evident when held vertically, and its neutrality also evident when its ends are reversed in the same magnetic field, we find that its polarity is equal at both ends, and that it is every way symmetrical with a perfect magnet. If we gradually reverse the ends and take observations of its condition through each degree of arc passed over, we find an equal symmetrical diminution of evident external polarity until we arrive at neutrality, when it has no external trace of inherent polarity, but its inherent polarity at once becomes evident by a simple return to its former position. Thus the rod has passed through all the changes from polarity to neutrality, and from neutrality to polarity, and these changes have taken place with complete symmetry.

The limits of this paper do not allow me to speak of the numerous theoretical evidences as shown by the use of my induction balance. I believe, however, that I have cited already experimental evidences to show that what has been attributed to coercive force is really due to molecular freedom or rigidity; that in inherent molecular polarity we have a fact admitted by Coloumb, Poisson, Ampère, De la Rive, Weber, Du Moncel, Weidermann and Maxwell; and that we have also experimental evidence of molecular rotation and of the symmetrical character of polarity and neutrality. The experiments which I have brought forward in this paper, in addition to those mentioned in my paper read before the Royal Society, will, I hope, justify me in having advanced a theory of magnetism which I believe in every portion allows at least experimental evidences of its probable truth.

Spanish Copper Tubes. — The Metallurgiçal Society of San Juan de Alcarez has succeeded in manufacturing excellent copper tubes without soldering, so as to be able to compete with all other manufacturers, both in quality and in price. The mode of manufacture is new, and application has been made for a patent.—*La Gaceta Industrial*, Jan. 25, 1883. C.

NATIONAL EXHIBITION OF RAILWAY APPLIANCES, CHICAGO, ILL.

At the last stated meeting the Institute kindly passed a resolution accrediting me as its representative to the National Exhibition of Railway Appliances, now being held at Chicago, with the special duty of looking after the electrical exhibits, and I purpose now to give you a very brief report of my observations.

First, then, the Exhibition is a success, as such, but financially it is not likely to profit its projectors. This is due to the fact that it did not secure the hearty support of the local press.

As is usual with exhibitions, everything was in a very incomplete state on opening day, and there was the usual struggle for space by late exhibitors. On my first visit to the building, I called upon the Secretary and Directors, and learned from them that the greater part of the work and responsibility had fallen upon two or three gentlemen and that the burden was much too heavy. This would account for much of the confusion in the installation, which appeared as late as the second week of the exhibition. I found it impossible to get even a list of the electrical exhibits, much less learn where they were located, and I therefore hunted them up, and am not yet certain that I saw them all.

Confining myself, then, entirely to electrical apparatus, and passing by the many large displays of machine tools, forgings, etc., made by Philadelphia manufacturers, I would classify the electro-magnetic apparatus on exhibition under the heads Railway Signals, Magnetic Brakes, Electric Lights, Electro-Motors, and General Electrical Supplies.

As the Franklin Institute is now preparing for an electrical exhibition, it might be well to consider early a question which has bothered the managers of the Chicago exhibition, and that is, What to admit and what to reject? One of the first remarks made by a visitor on entering the building is that there are many things there which do not seem to have any connection with railroads, such as type-writers, paper-hangings, etc. One exhibitor complained that he was not allowed to exhibit envelopes because, he said, they were largely used by railroad companies. The Secretary, however, told him that they had concluded to draw the line at envelopes.

At first glance it might seem that it would be difficult to secure for an electrical exhibition a sufficient variety of articles to make a respectable show, but electricity has within a few years invaded so many fields hitherto occupied by other agencies, that before another year is upon us it may be necessary to draw the line closely and exclude much that would occupy space to the detriment of more appropriate articles.

The experience at Chicago shows what has often been demonstrated in this city, that the interest is largely increased by showing everything in motion that is made to move. Instruments should be so shown as to demonstrate at a glance what they are made for; otherwise it may be difficult to make such an exhibition as the Franklin Institute Exhibition of 1884 a popular one. An electric motor which does not move tells no tale except to the expert, and a Leclanché cell so placed that its use is not apparent, might as well be a jar of pickles.

To return to the exhibits, my attention was first called to the various systems of automatic electric railway signals, of which I made a special study. Only two of these appear to have been well digested; and I may here remark that it is surprising how many inventors cudgel their brains to get up apparatus which is of no earthly use, because they have not duly considered the conditions under which the appliances must be used. Automatic signals to be of any value must cover every possible case; must provide for every position of trains; but the majority of those exhibited seemed to have been gotten up with the idea that the only danger to be guarded against was that a train might be overtaken by a following train or run into an open draw. Unless provision is made for every case which could by any possibility arise, there is no likelihood of any automatic system being adopted on any well-regulated railroad. This is only another illustration that the best inventions originate with the workmen and spring from the necessities of the case.

There are two general systems, one of which uses the railroad track for the electric circuit, and the other uses wires either carried on poles or in cables. The Union Switch and Signal Company, of Pittsburg, exemplifies the first, and the Hall Railway Signal Company, of Meriden, Conn., the second system, and each seems to have fairly compassed the problem of automatic signalling. Both are in practical operation on railroads in this country.

Messrs. Crandell & Strohm, of this city, exhibit an automatic block

system in operation which does not throw up visible signals, but which is intended to operate by shutting off the steam and putting on the air-brakes whenever the train enters a block which is not clear. Other systems are exhibited which aim to accomplish the same result.

The perfection of the Westinghouse air-brake would seem to close the field against any brake operated by a different method. The use of this brake, however, has hitherto been confined to passenger trains or short stock trains. This leaves a field for a good magnetic brake for freight trains, and two very creditable brakes of this character were shown. Both are actuated by a dynamo upon the locomotive, and one supplements this by a storage battery in each car to operate the brakes when the car is separated from the locomotive. There are several practical objections to these brakes in their present state of development, but a thoroughly good magnetic brake may yet be perfected.

The electric light was represented by five different systems of arc and incandescence lights. We are all now so familiar with the arc lights that I may simply say that they were all very good and all claimed to be the best. I may say, however, that one system had many admirers, and its lights, which were scattered plentifully through the whole space, were complimented for their beauty and steadiness. The inventors of that system are our honored associates Messrs. Thomson and Houston. The incandescence lights of the Maxim, Edison, and Swan systems were in endless profusion and much admired.

Electric motors did not show up very well. The only style was the Weston dynamo used as a motor on the Field & Edison Electric Railway, and in another place to operate a centrifugal pump for a waterfall. Prof. Sylvanus Thompson says there is a great field for electric transmission of power, but if the inventions thus far made public are the best that our inventors have developed, we have not yet climbed the fence. So far as the public are concerned, the electric railway is a success; the people stand in line for a chance to ride on it. But at what expense of power is the motor and loaded car, weighing in all perhaps four tons, propelled? On investigation I found that an 18 horse-power engine was not equal to the task of moving the train, and the gates were shut against the public until the wires were connected with a 40 light dynamo run by a much more powerful engine. In like manner the dynamo which operated the pump was a 5 or 6 light machine run by a 40 light dynamo.

The improvements in dynamos are chiefly in the new regulators for

reducing the power to correspond with the reduction in work performed.

The storage battery made no show and seems to have been withdrawn from the public for a time.

In conclusion I would say that although the display at Chicago is a fine one and well worth a visit, I think we do these things better in Philadelphia, and the Franklin Institute with its long experience and excellent organization will have no trouble in arranging an exhibition more extensive, more attractive, and much more valuable in its results.

E. ALEX. SCOTT.

Photo-Zincography.—In the office of the French Minister of Public Works, charts and plans are prepared by a process of photo-zincography. A plate of commercial zinc is chosen which is free from defects. In order to cleanse it thoroughly it is rubbed with a stiff hair brush, which is dipped into a mixture of one-third sulphuric acid and two-thirds water. After this cleansing, which removes every trace of oxidation and grease, the plate becomes very brilliant, and it is rubbed for some minutes by a cork dipped in powdered pumice stone. It is then washed and plunged, for ten or fifteen minutes, into a bath acidulated with three per cent. of nitric acid. The plate then has a dull look and shows a slight roughness under the microscope. After having carefully dried it, it is covered by a preparation composed of 10 litres of water and 500 grammes of crushed nutgalls. After boiling this preparation until it is reduced about one-third, it is cooled and filtered through linen; then are added 100 grammes of common nitric acid and 6 grammes of pure chlorhydric acid. After the preparation has been left in contact with the plate for some time it is washed and dried, and then coated with bitumen in the ordinary manner, and exposed to the light under the drawing which is to be copied. When the exposure is over, the plate is warmed slightly and developed with the addition of a liquid containing 5 per cent. of acetic acid. To facilitate the inking, it is well to apply to the lines some oil, which destroys their brilliancy and turns them gray. Then, after a careful drying, the bitumen is dissolved by benzine, and the plate is again dried. It can then be delivered to the printer, who submits it, without any precautions, to the customary operations of lithography for inking and printing.—*Bul. de la Soc. d'Encour.*, Jan., 1883. C.

Orange Peel.—A special application has lately been made of an article that has hitherto been thought nearly worthless. It is well dried in an oven, and then used for kindling fires, for which its essential oil admirably fits it.—*Gaceta Industrial*, March 10, 1883. C.

Constitution of the Sun.—In the third part of his discussion of the physical and mechanical constitution of the sun, Faye states that the solar refraction is insensible, and he has been able definitely to establish the fact that the mean depth of the spots is fully $\frac{1}{200}$ of the solar radius, or more than 2,000 miles. This power of penetration is not peculiar to the sun; it is found to a high degree in our own atmosphere. A cyclone, or a tornado, which begins in the region of the cirrus clouds, at a height of four or five miles, descends vertically to the ground; if in its course it meets a deep valley, it descends again until it touches the new soil, on which it manifests the same strength as upon an elevated plateau. On the sun the obstacle is not the soil; it is the specific lightness of the gases, which are drawn into layers of increasing density until the work of which the whirl is capable has been completely exhausted. In our cyclones and tornadoes, which draw only air, and not a gas which is specifically lighter than air, the air possesses nearly the same density as that of the surrounding medium; there is, therefore, only a feeble ascensional tendency. The atmospheric equilibrium is re-established without the return of the whirling air to the higher regions. It is evident that the case must be far otherwise in the sun, where the descending gas is hydrogen. This gas, superheated in the lower regions, will soon remount far above its point of original departure and above the chromosphere; that is to say, into the almost complete vacuum of the coronal region, giving place to that astonishing apparition of luminous protuberances, which the beautiful discovery of Janssen and Lockyer allows us to study daily on the sun's circumference. This hydrogen is often seen to fall back to the sun in different forms; sometimes in tongues of fire, imitating a sort of rain, at other times by a collective movement, as if by a slow subsidence. The chromosphere, which is receiving the materials of these protuberances, does not sensibly change its level. The circulation of the hydrogen is, therefore, mostly vertical and due to gyrations of different magnitudes in the photosphere. The formation of faculæ and pores, and the various other changes of the sun's surface, are all explained mechanically by the same gyratory movements. —*Comptes Rendus*, Feb. 5, 1883. C.

Color of Distilled Water.—M. Meyer, of Zurich, has devised the following experiment: He encloses by parallel panes of glass a tube 7·5 metres (35·37 feet) long and with an interior diameter of 4 centimetres (1·575 inches). This apparatus, being filled with distilled water and placed horizontally, on looking through it at a black ground in the sunlight it appears of a deep intense blue. If, on the contrary, gas light is employed, a green color is perceived.—*Les Mondes*, Jan. 13, 1883. C.

Deep Sea Explorations.—Twenty-five years ago, Thomas Bell wrote the last pages of a history of the British crustacæ. He thought that he had raised a lasting monument, and flattered himself that his successors could add little to the information which he had given. The facts which have been subsequently discovered have profoundly modified the ideas of naturalists. It was supposed that life is impossible in the depths of the sea, and that the waters are condemned to obscurity, solitude and immobility. The pressure of the water, the absence of light, the slowness of the renewal of the water, the want of algæ or other vegetable materials, and the experiments of Prof. Edward Forbes upon the diminution of animal life with increasing depth, in the Egean Sea, were supposed to prove that life cannot exist at a greater depth than 450 metres (492 yds.) When Captains Ross and Wallich found some animals upon their sounding lines, which had descended to a depth of more than a kilometre ($\frac{5}{8}$ of a mile), it was thought that they had either been entangled near the surface or that they had fallen to the bottom after their death. In 1860, the cable between Sardinia and Algiers was broken, and numerous animals were found upon the gutta percha insulating surface. M. A. Milne Edwards was consulted upon the subject, and he found conclusive evidence that they had been born and developed at a depth of more than two kilometres (1·243 miles.) These discoveries awakened great interest and led to the preparation of the steam cutter *Travailleur*, in 1880, for a scientific exploration of the sea depths. The cutter has been employed in each of the three past summers, in the Gulf of Gascony, on the shores of the Iberian peninsula, Corsica, Algiers and Morocco, in the Strait of Gibraltar and at the Canary Islands, yielding an immense number of animals which were previously unknown, many of which were drawn from depths of more than 5 kilometres (3·1 miles).—*Am. de Chim. et de Phys.*, Dec., 1882. C.

Generation of Inflammable Gases in the Diffusion of Beets.—In extracting sugar from beet roots by diffusion, gases are liberated which sometimes take fire and burn with a bluish flame. L. Chevron has analyzed the escaping gases and finds that they consist at first only of carbonic acid and nitrogen. After awhile hydrogen begins to appear, which seems to be due to an acid reaction of the beet juice upon the iron with which it is in contact. He thinks it would be impossible for the hydrogen to accumulate in sufficient quantities to produce an explosion, but the inevitable corrosion of the diffusives by the acid juice is an inconvenience which should be guarded against.—*Bul. de l'Acad. de Belg.*, 1883. C.

Amber.—Natural amber is distinguished from artificial amber, or from other materials to which it has some resemblance, by the following characteristics: Copal is yellow, and always of a uniform color. Amber, on the other hand, has usually different shades at its two extremities. Amber exhales an aromatic odor when rubbed on the palm of the hand. This is not the case with copal or with artificial amber. Amber, when covered with tallow, and held for some minutes over a flame, inclines to bend, Artificial amber and copal do not bend. Natural amber is always harder than artificial amber and copal. It is crushed with difficulty, and is not so easily affected by rubbing with a finger-nail. It may be cut, filed, sawed or polished, but cannot be welded like copal and artificial amber. Natural amber only melts at a heat of 400° (688°F.). Cigar holders of artificial amber melt as soon as the light of the cigar reaches them. Copal does not melt, but splits.—*Chron. Industr.*, Jan. 7, 1883. C.

OBITUARY.—BENJAMIN HOWARD RAND.

Benjamin Howard Rand, son of Benjamin and Eleanor Spurrier Rand, was born in Philadelphia, October 1st, 1827. His professional studies were begun in 1843, under the eminent Dr. Robert M. Huston, the then Dean of Jefferson Medical College; he subsequently attended the usual courses of lectures at Jefferson Medical College. In 1848 he received his degree of M.D. from that institution. During the last two years of his student life he was clinical assistant to Professors Mutter and Pancoast. In 1850 he was elected Professor of Chemistry in the Franklin Institute, holding that position until his resignation

in 1864. Upon the foundation of the Philadelphia Medical College —an institution which ceased to exist in 1861—he was elected to the chair of chemistry, and from 1852 to 1864 he was secretary to the Academy of Natural Sciences. This latter office, as well as his professorship in the Franklin Institute, he resigned in 1864, to accept the chair of chemistry in Jefferson Medical College, from which he resigned in May, 1877, on account of ill health. He was elected a fellow of the Philadelphia College of Physicians in 1853, and a member of the American Philosophical Society in 1868. He was also a member of the American Medical Association.

Besides frequent contributions to scientific periodicals he has written "Chemistry for Students," 1 vol., pp. 259 (1855), "Elements of Medical Chemistry," 1 vol., pp. 420 (1863 and 1875), and also edited Metcalfe's "Caloric," 2 vols., 1859.

Dr. Rand has been for some years in failing health. He died on the 14th of February, 1883, at the age of fifty-five.

Franklin Institute.

HALL OF THE INSTITUTE, June 20th, 1883.

The meeting was called to order at the usual hour, with the President, Mr. Wm. P. Tatham in the chair. Present, 82 members.

The minutes of the last meeting were read and approved.

The Actuary submitted the minutes of the Board of Managers, and reported that at the stated meeting held June 13th, 8 persons had been elected to membership.

He also reported under instructions from the Board, the following correspondence referred to the Institute, viz.:

OFFICE OF THE MAYOR OF THE CITY OF PHILADELPHIA,
PHILADELPHIA, June 7th, 1883.

To the Managers of the Franklin Institute of Philadelphia:

GENTLEMEN:—I enclose a copy of an ordinance passed by the Councils of this City and approved May 28, 1883, entitled "An ordinance to authorize the Mayor to appoint a Board of Experts to report on the present system of paving the streets of Philadelphia."

Your attention to this ordinance would be appreciated.

Your early reply will oblige

Yours respectfully,
SAMUEL G. KING,
Mayor of Philadelphia.

AN ORDINANCE

To authorize the Mayor to appoint a Board of Experts to report on the present system of paving the streets of Philadelphia, and to devise a better system.

SECTION 1. *The Select and Common Councils of the City of Philadelphia do ordain*, That the Mayor of Philadelphia be, and he is, hereby requested to obtain from the American Society of Civil Engineers, the Engineer Corps of the United States Army, and the Franklin Institute of this City, the names of six engineers, two to be selected by each of the above bodies as eminent in their profession and with particular reference to their knowledge and experience of the best system of pavement for the streets of large cities, due regard being had to its healthfulness, economy, smoothness, durability, and drainage, and that from said six names, of two to be selected by each of the above bodies, his Honor the Mayor be, and he is, hereby requested to select one from each body, and to constitute the three so chosen a Board of Experts.

SEC. 2. The duty of this Board shall be to point out to Councils the defects of the present system of paving the streets of Philadelphia, and, in comparison with the advantages of the Belgian block system, to make a thorough and exhaustive report of the most durable and best pavement that can be devised by them for said streets, particular regard being had to its healthfulness, economy, smoothness, durability, and drainage, and estimating the probable cost of a better system.

SEC. 3. The compensation of the said engineers is not to exceed one thousand dollars, inclusive of all individual expenses.

Warrants to be drawn on item 3 of ordinance of June 21, 1882, for the repaving streets with Belgian blocks or other improved pavement.

Approved May 28, 1883.

On the motion of Mr. Hector Orr, seconded by Mr. J. E. Mitchell, it was

Resolved, That we duly appreciate the compliment implied in the request of our City Councils, and hereby authorize the Board of Managers to comply with the same without delay.

Mr. E. Alexander Scott, the accredited representative of the Institute at the National Exhibition of Railway Appliances at Chicago, presented a report which appears elsewhere in this issue of the JOURNAL. By invitation, Mr. Robert Grimshaw made some remarks on the mechanical features of that Exhibition.

The Secretary, on behalf of the Committee on Science and the Arts, reported by instruction that the Committee had recommended the award of the John Scott Legacy Medal and Premium to James Beecher, of Philadelphia, for his Improvement in the Manufacture of Hollow-Handled Cutlery; to Henry Whitall, of Philadelphia, for his Celestial Planisphere; and to Robert Hitchcock, of Watertown, N. Y., for his Improvement in Mechanical Lamps.